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COMPARISON OF CONFORMATION, ANATOMY, AND SKELETAL STRUCTURE OF THE COW AND BULL OF A DAIRY BREED[1]

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INTRODUCTION

A comparison of the conformation, anatomy, and skeletal structure of two cows representing the highly specialized dairy and the highly specialized beef types was presented in a previous paper.[2] Although these cows were found to differ greatly in external form, the differences in weight and size of their internal organs were not sufficient to indicate significant differences in function, and their skeletal structure was similar in most particulars. Except for the extreme differences in external form, the quantity of secretory tissue in their udders was the most striking difference noted. These findings led to the conclusion that the evolution of the dairy and beef types, which has been accomplished through breeding and selection over a period of many years, has not materially altered their skeletal structure, but that the difference in type is due to extreme fleshing on the one hand and to udder development and absence of fleshing on the other. The results of this study suggested the advisability of making a similar comparison of the conformation, anatomy, and skeletal structure of a cow and a bull of the same breed.

Sophie 19th of Hood Farm 189748, whose anatomical data had already been completed and published, was chosen for this study. She had made a world's record by producing 17,557.8 pounds of milk and 999.1 pounds of butterfat in one year. She had also made a world's record for lifetime production by producing 7,544.51 pounds of butterfat in 11 yearly official records. The bull used for comparison was Majesty's Fern's Noble Fox 193952, a representative specimen of the Jersey breed. For the sake of brevity, Sophie 19th of Hood Farm and Majesty's Fern's Noble Fox will subsequently be referred to as "the cow" and "the bull."

The average weights of Jersey cows and bulls are about 900 pounds and 1,500 pounds, respectively.[3] When the cow was measured she was in fair flesh and weighed 927 pounds. She would probably be considered somewhat above the average for the breed in size—especially in frame. The bull was in good flesh and weighed 1,500 pounds

[1] Received for publication Mar. 9, 1932; issued November, 1932.

[2] SWETT, W. W., GRAVES, R. R., and MILLER, F. W. COMPARISON OF CONFORMATION, ANATOMY, AND SKELETAL STRUCTURE OF A HIGHLY SPECIALIZED DAIRY COW AND A HIGHLY SPECIALIZED BEEF COW. Jour. Agr. Research 37: illus. 685–717. 1928.

[3] NYSTROM, A. B. DAIRY CATTLE BREEDS. U. S. Dept. Agr. Farmers' Bull. 1443, p.26. 1930.

when the ante-mortem data were obtained. He can, therefore, be considered as of average size for the breed. The cow was 19 years and 4 months of age and the bull was 6 years and 6 months of age. Photographs of the living animals are shown in Figures 1–3.

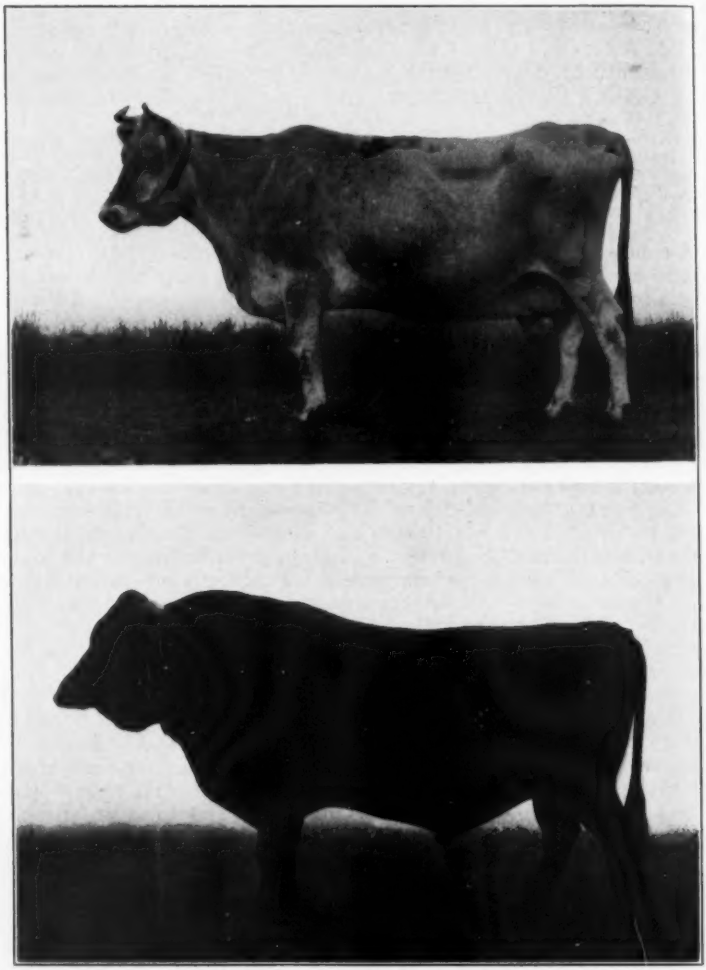

FIGURE 1.—Side view of cow and bull

ANTE-MORTEM DATA

The conformation or type of an animal must be expressed in numerical terms before it can be analyzed or compared with that of another. This is accomplished by making a number of external measurements, so selected that they represent the size, proportions, and outlines of the body. The method of measuring adopted by the

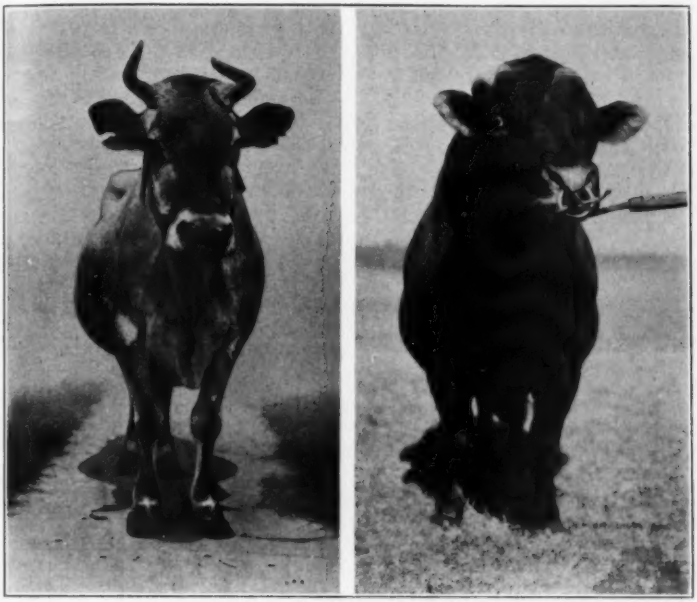

FIGURE 2.—Front view of cow and bull

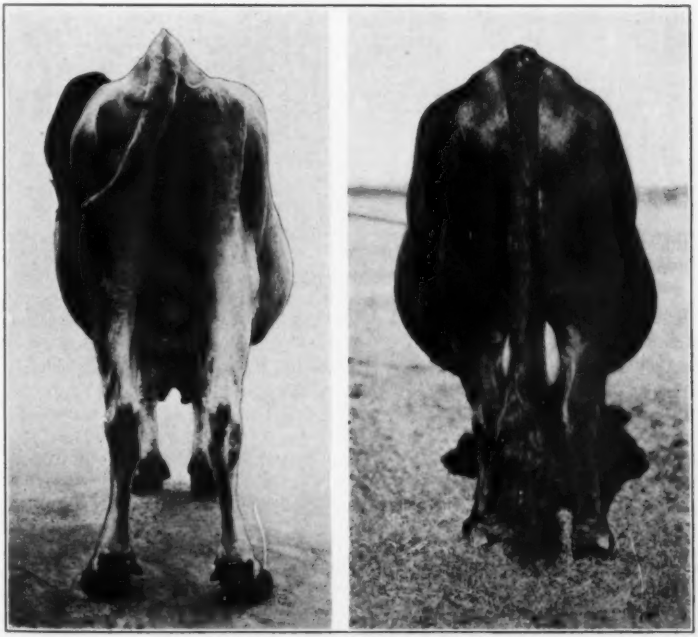

FIGURE 3.—Rear view of cow and bull

Bureau of Dairy Industry for studying growth, and the relationship between conformation, anatomy, and producing capacity of dairy cows, was applied in making this comparison. The difficulties experienced in measuring the Aberdeen Angus cow [4] were not encountered in the case of this bull as he was not carrying an excessive amount of flesh. The ante-mortem data in this comparison are, therefore, more nearly representative of the actual conformation of the animals, since the body landmarks were readily located. The external body measurements which represent the conformation of the cow and the bull, together with the relation of the measurements of the bull to those of the cow, expressed in percentage, are given in Table 1.

TABLE 1.—*Ante-mortem external measurements of cow and bull*

Item measured	Instrument used	Unit	Cow	Bull	Relation of measurements of bull to those of cow
					Per cent
Thickness of hide	Vernier caliper	Centimeters	0.66	1.16	175.8
Live weight		Pounds	927.00	1,500.00	161.8
Height at withers	Measuring standard.	Centimeters	128.17	128.06	99.9
Height at hips	do	do	122.50	125.31	102.3
Height at pin bones	do	do	117.00	121.50	103.8
Length, top hips to top pin bones (length of rump).	Tape line	do	41.00	42.50	103.7
Depth of fore chest	Caliper	do	71.50	73.50	102.8
Depth of rear chest	do	do	71.00	76.00	107.0
Depth of paunch	do	do	71.17	80.00	112.4
Width of fore chest	do	do	36.17	50.00	138.2
Width of rear chest	do	do	56.33	67.00	118.9
Width of paunch	do	do	60.17	73.50	122.2
Width of hips	do	do	48.00	50.25	104.7
Width of pin bones	do	do	29.50	32.00	108.5
Width of thurls	do	do	43.00	44.50	103.5
Width of loin	do	do	29.00	32.50	112.1
Length, withers to line between hips	Tape line	do	88.50	92.00	104.0
Length, line between hips to pin bones	do	do	53.00	51.00	96.2
Total length from withers to pin bones	do	do	141.50	143.00	101.1
Length of loin	do	do	38.00	37.00	97.4
Circumference of fore chest	do	do	177.67	209.00	117.6
Circumference of rear chest	do	do	203.67	229.00	112.4
Circumference of paunch	do	do	213.67	249.00	116.5
Width of forehead	do	do	22.00	29.00	131.8
Circumference of muzzle	do	do	44.00	56.00	127.3
Length from poll to mouth	do	do	56.00	61.00	108.9
Circumference of shin bone	do	do	16.50	19.00	115.2

The percentage value in each instance shows the relation of the measurement of the bull to that of the cow. A value above 100 indicates a greater measurement for the bull than for the cow, and a value below 100 indicates a greater measurement for the cow than for the bull. Comparing the conformation of the two animals on the basis of these percentage values is more significant than comparing them on the basis of the difference in units of measurement, for a difference of 1 cm in one body measurement may be proportionately as great as a difference of 10 to 15 cm in some other measurement. For example, a difference of 2.5 cm in circumference of

[4] SWETT, W. W., GRAVES, R. R., and MILLER, F. W. Op. cit.

shin bone gives a percentage of 115.2, whereas a difference of 35.33 cm in circumference of paunch gives a percentage of 116.5.

The highest percentages are for thickness of hide and live weight, neither of which is indicative of conformation. Of the 25 measurements which are indicative of skeletal size, body proportions, or conformation, the one having the highest percentage is width of fore chest and the one having the lowest percentage is the length from a point midway between the hips to the pin bones.

Five groups of items representing (1) lengths, (2) heights, (3) depths, (4) widths, and (5) circumferences have been studied separately.

Percentages for the measurement of length range from 108.9 to 96.2, and average 101.9 when the length of head (poll to mouth) is included and 100.5 per cent when omitted. This shows that the two animals differed very little in length.

The three percentages for height range from 103.8 to 99.9 and average 102.0, showing that in height of body also the two animals were nearly the same.

The percentages for depth of body range from 112.4 to 102.8 and average 107.4, indicating that the depths of the two animals differed relatively more than either the lengths or heights, but were not extreme.

Body widths are not entirely consistent in their relationships. The percentages range from 138.2 to 103.5. The average of the eight which constitute this group is 117.5, but if the width of forehead is excluded the average is reduced to 115.4. Three (width of fore chest, rear chest, and paunch) apply to barrel measurements. They range from 138.2 to 118.9 and average 126.4. Four of the widths (loin, pin bones, hips, and thurls) are measurements of body dimensions but are more significant of skeletal width than are the three barrel widths. The range for these four skeletal widths is from 112.1 to 103.5 per cent and the average is 107.2 per cent. In relative width of body the bull was, therefore, considerably greater than the cow.

Five circumferences were measured. The percentages range from 127.3 to 112.4 and average 117.8. The exclusion of circumference of muzzle and circumference of shin bone reduces this average to 115.5. The circumferences of the bull are, therefore, distinctly greater than those of the cow, and represent the highest average percentage of any group.

The average of the percentages for the entire group of 25 body measurements is 110.7, which shows that the bull, in general, was larger than the cow but that the difference in measurements does not approach the difference in live weight. This is true not only of the averages for any group but for every individual item measured. The exclusion from group averages, of length from poll to mouth, width of forehead, circumference of muzzle, and circumference of shin bone, has been made because in some respects these items may not be as indicative of body size or body scale as the others.

As a supplement to the data in Table 1, a number of additional items were derived in order to determine more completely the relation between the conformation of the cow and of the bull. The results are given in Table 2.

TABLE 2.—*Supplemental ante-mortem data and factors showing relation between conformation of cow and bull*

	Cow	Bull	Relation of conformation of bull to conformation of cow
Contour area of fore chest:			*Per cent*
Total ..... square centimeters	1,882	2,762	146.8
Portion above vertical mid-point ..... do	973	1,416	145.5
Portion below vertical mid-point ..... do	909	1,346	148.1
Percentage of total above vertical mid-point ..... per cent	51.7	51.3	.....
Percentage of total below vertical mid-point ..... do	48.3	48.7	.....
Contour area of paunch:			
Total ..... square centimeters	3,226	4,559	141.3
Portion above vertical mid-point ..... do	1,425	2,018	141.6
Portion below vertical mid-point ..... do	1,801	2,541	141.1
Percentage of total above vertical mid-point ..... per cent	44.2	44.3	.....
Percentage of total below vertical mid-point ..... do	55.8	55.7	.....
Slope of rump ..... degrees-minutes	−7 43	−5 9	66.7
Thoracic index ..... ratio	1.977	1.470	74.4
Abdominal index ..... do	1.183	1.088	92.0
Volume of barrel ..... cubic centimeters	226,029	336,766	149.0
Body-surface area ..... square centimeters	47,470	57,912	122.0
Legginess ..... ratio	0.442	0.426	96.4
Wedge shape:			
Difference in measurements—			
Depth of paunch minus depth of fore chest ..... centimeters	−0.33	+6.50	.....
Width of paunch minus width of fore chest ..... do	+24.00	+23.50	.....
Circumference of paunch minus circumference of fore chest ..... centimeters	+36.00	+40.00	.....
Contour area of paunch minus contour area of fore chest ..... square centimeters	+1,344	+1,797	.....
Ratio of measurements—			
Depth of paunch to depth of fore chest ..... ratio	0.995	1.088	109.3
Width of paunch to width of fore chest ..... do	1.664	1.470	88.3
Circumference of paunch to circumference of fore chest ..... do	1.203	1.191	99.0
Contour area of paunch to contour area of fore chest ..... do	1.714	1.651	96.3

At the time the ante-mortem measurements were made with tape line, measuring standard, and calipers, contours or cross-section outlines of the body at the fore chest and paunch were drawn life-size on specially ruled sheets of paper. An apparatus designed and constructed for the purpose was used in making the contours. In many respects contours are more significant than caliper measurements, for two animals that have identical vertical and transverse measurements may differ greatly in cross-section areas as a result of differences in shape. For example, the chest of one may be full and rounded whereas that of another may be constricted above or below the point of maximum width. Again, the paunch of one may be round and full with the maximum width near the vertical mid-point, whereas that of another may be "slab-sided," with its maximum width near the lower extremity of the vertical axis. The areas of the contours were measured with a planimeter. A study of a large number of body contours throws some light on the distribution of the cross-section area of the body at different planes. The writers expect to study the relation of that distribution to the size of some of the internal organs. The contours of the fore chest of the cow and bull are illustrated in Figure 4; those of the paunch are shown in Figure 5.

Both of the percentages showing the relation between the total contour area of the bull and that of the cow at the fore chest and at the paunch (146.8 and 141.3, respectively) are higher than any of those representing body conformation in Table 1. To determine the disributtion of a contour area, the procedure regularly followed

is to divide each contour into two parts by drawing a horizontal line through a point on the median line exactly halfway from its highest to its lowest extremity. The two areas formed by the horizontal line through the vertical mid-point are measured separately and are referred to as the portions above and below the vertical mid-point. Although wide variations in the distribution of the areas of contours have been found to occur with other animals of the same breed, the distribution for fore chest and for paunch is remarkably similar for the cow and bull. In the fore-chest contours the portions above and below the vertical mid-point were, respectively, 145.5 and 148.1

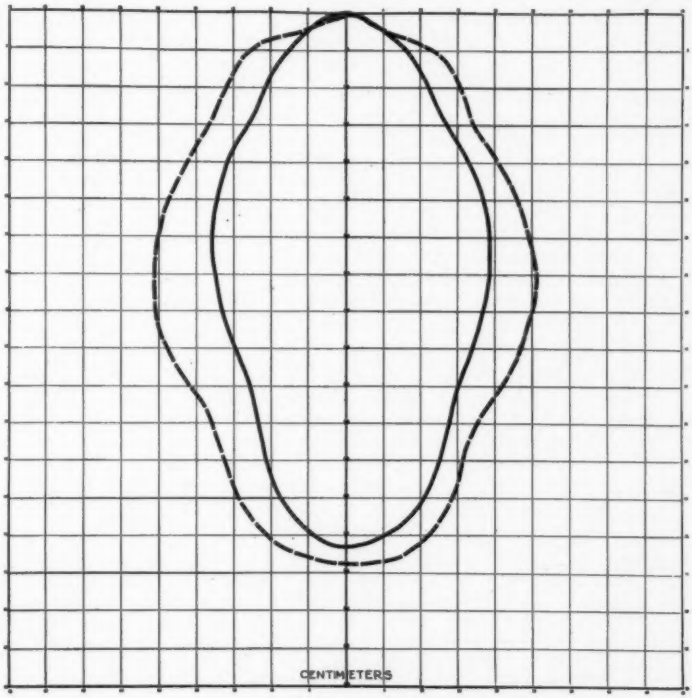

FIGURE 4.—Contours of fore chest (cow, solid line; bull, broken line)

per cent as great for the bull as for the cow. Both of these percentages are similar to the percentage (146.8) representing the relationship between the total fore-chest areas. Also, the portion of the total area above the vertical mid-point was 51.7 per cent for the cow and 51.3 per cent for the bull.

The similarity of distribution of areas in the fore-chest contours of the two animals is shown in every comparison in spite of the fact that the two contours differ considerably in shape. (Fig. 4.) The contour areas of the paunch also differ in shape, although both indicate a deep but slab-sided barrel. (Fig. 5.) As in the case of the fore chest, both of the percentages which show the relation of bull to cow

for the portions above and below the vertical mid-point are very close to the corresponding one for total paunch areas. Although slightly more than half the total area of the fore chest was above the vertical mid-point, considerably more of the paunch was below the vertical mid-point in both the cow and the bull. This is in accord with observations that both animals were deep in the paunch and inclined to be slab-sided. The distribution of paunch areas for the cow and bull is surprisingly similar.

The slope of rump, or its angle of inclination from the horizontal, was calculated on the basis of the difference between the height at

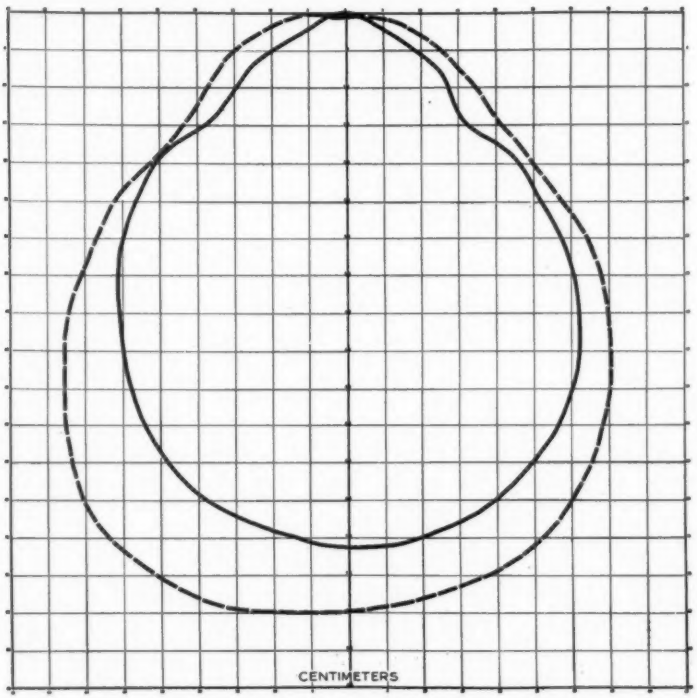

FIGURE 5.—Contours of paunch (cow, solid line; bull, broken line)

hip and the height at pin bone and the linear distance between these two points. When the pin bone is lower than the hip point the angle of rump is minus; when the pin bone is higher than the hip point it is plus. The angle of inclination, or slope of rump, of the bull was $-5° 9'$ as compared to $-7° 43'$ for the cow. The percentage showing the relation of the slope of rump of the bull to that of the cow (66.7) is distinctly misleading, as it indicates a wide difference between the two animals. However, in consideration of the fact that the angles of rump measured in the writers' studies with a large number of animals have varied from $+9° 36'$ to $-18° 58'$, a total range of $28° 34'$, the difference in angle between the cow and bull is almost negligible.

The thoracic index is the relation of depth to width of fore chest. The thoracic indexes indicate that the fore chest of the cow is relatively deep and narrow, whereas that of the bull is decidedly wider in proportion to its depth.

The abdominal index is the relation of depth to width of paunch. The abdominal indexes show that the bull was only slightly wider than the cow in proportion to depth of paunch.

Volume of barrel is an approximation obtained by multiplying one-half the sum of the fore-chest and paunch-contour areas by the length from withers to a line between the hips. The volume of the bull was 149 per cent as great as that of the cow. This percentage is similar to those for contour areas of fore chest and paunch, and is higher than any other percentage showing the relation between the measurements of the bull and the cow, except thickness of hide and live weight, neither of which is indicative of skeletal size, body proportions, or conformation.

The body-surface area was calculated by the Hogan and Skouby [5] formula ($S = W^{.4} \times L^{.6} \times K$), in which S = surface of body in square centimeters, W = live weight in kilograms, L = length from withers to pin bones in centimeters, and K = a constant, which for cattle is 217. The area of the bull was 122 per cent as great as that of the cow, which is near the maximum of the percentages representing the relation of the conformation of the bull to that of the cow, and higher than the average for any major or minor group of measurements except the average for the three widths of barrel (126.4 per cent) taken at the fore chest, rear chest, and paunch.

Legginess is the relation of length of forelegs to height at withers and is determined by dividing the length of forelegs by the height at withers. Length of forelegs is determined by subtracting the depth of fore chest from the height at withers. The two animals did not differ greatly in legginess.

The wedge shape of an animal is the amount of divergence between the opposite walls of the barrel. It is determined by comparing the measurements of the paunch with those of the fore chest and is expressed in two ways: (1) The difference in units of measurement between the depths, widths, circumferences, and contour areas of the paunch and fore chest, and (2) the ratio of the depth, width, circumference, and contour area of the paunch to the depth, width, circumference, and contour area of the fore chest. The two animals differed considerably in wedge shape. The cow was slightly deeper at the chest than at the paunch, but the bull was 6.50 cm deeper at the paunch than at the chest, showing that the vertical wedge of the bull was decidedly greater than that of the cow. Other differences in wedge shape are shown in Table 2.

Since the bull was much larger and heavier than the cow, one might expect a greater difference in units of measurement between the paunch and fore chest of the bull than between those of the cow. However, the ratios of the paunch measurements to the fore-chest measurements of depth, width, circumference, and contour areas for the cow and bull may be independent of the size of the animal, provided the distances between the planes used in measuring the fore chest and paunch of the cow and the bull do

[5] HOGAN, A. G., and SKOUBY, C. I. DETERMINATION OF THE SURFACE AREA OF CATTLE AND SWINE. Jour. Agr. Research 25 : 419-430, illus., 1923.

not differ materially. The average for all the length measurements of the body, except the length of the head, is 100.5 per cent and the length from withers to hips is only 104.0 per cent as much for the bull as for the cow. These differences are among the lowest recorded for any of the body measurements.

As an illustration of the relative significance of the differences in units of measurement between paunch and fore chest and of the ratios between these measurements, let it be assumed that one animal measures 20 cm in width of fore chest and 30 cm in width of paunch, while another measures 40 cm in width of fore chest and 60 cm in width of paunch. The difference in units of measurement would be 10 for the former and 20 for the latter. On this basis the value for the second animal would be 200 per cent as great as for the first. On the basis of ratios of paunch to fore chest, each would be 1.50 and the relation of one to the other would be 100 per cent. The differences in units of measurement are, therefore, less significant of the relative wedge shape of the two animals than are the ratios of the paunch to the fore-chest measurements. Because of this fact the percentages showing the relation of the conformation of the bull to that of the cow are omitted for the differences but are included for the ratios. The differences, however, show very effectively the "reverse wedge" in depths for the cow, and that, although the bull is much larger than the cow, the difference between widths of paunch and fore chest is slightly greater for the cow than for the bull. This undoubtedly is due to the fact that the cow was deep and narrow in the fore chest and the bull was relatively much wider in proportion to his depth. This observation is in agreement with the thoracic indexes reported. Although differences in measurements would give one the impression that, except for width, the bull had greater wedge shape than the cow, the ratios themselves and the percentages indicate that the wedge shape of the bull was less than that of the cow in every measurement except depth.

POST-MORTEM DATA

A post-mortem study of the anatomy of the cow and the bull was made in accordance with the plan adopted by the Bureau of Dairy Industry for the purpose of determining the relation of conformation and anatomy to milk and butterfat producing capacity. The cow was killed by the injection of chloroform and the bull was killed by bleeding. The cow's lungs and liver retained large quantities of coagulated blood, so that these organs were excessive in weight and could not be compared satisfactorily with those of another animal. The bull's organs, when weighed, were all practically free of blood. The necessity for preserving the skeleton without injury prevented the recovery of the brain and pituitary body. The weights and measurements of the organs recovered which were not materially affected by blood retention, are listed for comparison in Table 3.

The term "empty body weight" is used in this study to represent the net weight of the total animal structure. It is determined by subtracting the total weight of the contents of stomachs and intestines from the live weight. Empty body weight is more significant than live weight because it eliminates variations due to differences in amount of feed or water consumed before weighing or to differences in intervals between feeding or watering and time of weigbing.

TABLE 3.—*Post-mortem data for cow and bull*

Item	Weight or measurement of organ or part				Relation of data of bull to those of cow	
	Cow		Bull			
	Actual units	Units per 100 pounds empty body weight	Actual units	Units per 100 pounds empty body weight	Actual units	Units per 100 pounds empty body weight
					Per cent	*Per cent*
Empty body weight.....pounds	768.50		1,329.30		173.0	
Weight of hide.....do	55.00	7.16	115.00	8.65	209.1	120.8
Weight of pancreas.....grams	(a)		640.00	4.81		
Weight of kidneys.....do	1,445.85	188.14	1,270.08	95.55	87.8	50.8
Weight of adrenals.....do	37.00	4.81	41.40	3.11	111.9	64.7
Weight of spleen.....do	822.15	106.98	1,542.24	116.02	187.6	108.5
Weight of liver.....pounds	(b)		20.60	1.55		
Weight of small intestine.....do	13.00	1.69	15.65	1.18	120.4	69.8
Weight of large intestine.....do	22.50	2.93	10.70	.80	47.6	27.3
Total weight of empty intestines.....do	35.50	4.62	26.35	1.98	74.2	42.9
Weight of intestine contents.....do	32.00	4.16	20.90	1.57	65.3	37.7
Length of small intestine.....feet	132.50	17.24	164.98	12.41	124.5	72.0
Length of large intestine.....do	34.00	4.42	41.98	3.16	123.5	71.5
Total length of intestines.....do	166.50	21.67	206.96	15.57	124.3	71.9
Total weight of empty stomachs.....pounds	47.00	6.12	37.05	2.79	78.8	45.6
Weight of stomach contents.....do	126.50	16.46	93.80	7.06	74.2	42.9
Weight of abdominal fat.....do	34.63	4.51	63.15	4.75	182.4	105.3
Weight of right lung.....do	(c)		4.80	.36		
Weight of left lung.....do	(c)		3.90	.29		
Total weight of lungs.....do	(c)		8.70	.65		
Circumference of heart (near base).....centimeters	45.00	5.86	45.50	3.42	101.1	58.4
Circumference of heart (over apex).....do	48.00	6.25	54.50	4.10	113.5	65.6
Weight of heart (auricles removed).....pounds	3.94	.51	4.75	.36	120.6	70.6
Weight of thoracic fat.....do	5.50	.72	3.80	.29	69.1	40.3
Weight of thyroid.....grams	23.00	2.99	72.00	5.42	313.0	181.3

[a] Pancreas omitted. [b] Liver abnormal. [c] Lungs filled with clotted blood.

Table 3 gives for the cow and the bull (1) the weight or measurement for each item, (2) the number of units of weight or measurement for each 100 pounds of empty body weight, and (3) the percentage relation of the anatomy of the bull to that of the cow on the basis of both. Twenty different items are compared. In 13 of these the weight or measurement for the bull is greater. In the group of 7 items which weighed or measured less for the bull than for the cow, 2 represent contents of the digestive tract which are subject to conditions of management and which consequently have little significance; 1 is the weight of thoracic fat, which probably is also of little significance; 2 are weights of empty intestines, which may be affected to a considerable extent by inability to remove all of the fat, and 2 are total weight of empty stomachs and weight of kidneys, both of which are readily prepared and comparable.

Although the weight of intestines is subject to some error as a result of adhering fat, the length of intestines can be measured readily and accurately. The length of the cow's intestine does not approach the maximum or the minimum recorded in a previous post-mortem study of many cows representing several breeds of dairy cattle.[6] The length of the bull's intestine, although considerably greater than that of the cow, is about 35 feet less than the maximum recorded in the study mentioned.

[6] Unpublished data in files of Bureau of Dairy Industry.

The retention of blood in the lungs of the cow prevented a determination of the total lung weight. The total lung weight of the bull was 8.70 pounds. For 229 cows slaughtered in a packing house, whose average empty body weight was 941 pounds, the average lung weight was 7.36 pounds. This is 0.78 pound for each 100 pounds of empty body weight for the 229 cows, as compared with 0.65 pound for the bull. Apparently the lung weight of the bull was comparatively low when considered on the basis of the weight of total animal structure.

The weight of the bull's heart was 4.75 pounds or 0.36 pound per 100 pounds empty body weight, as compared to 0.51 pound for the cow and 0.47 pound for 247 of the slaughterhouse cows previously mentioned. When the actual weight of the bull's heart is compared with that of the cow included in this study, or with the group of slaughterhouse cows, it is slightly high, but the weight for each 100 pounds of empty body weight is distinctly low. The measurements of the heart were slightly greater for the bull than for the cow when compared on the basis of the actual units of measurement.

The difference in empty body weight of the cow and the bull was 560.8 pounds as compared with a difference of 573 pounds in the ante-mortem live weight, and although the relation of bull to cow was 161.8 per cent in live weight, it was 173.0 per cent in empty body weight. A comparison of the other post-mortem data of the two animals on the basis of the actual units of weight or measurement shows that the values range from a maximum of 313.0 per cent for weight of thyroid to a minimum of 47.6 per cent for weight of large intestine. Whereas in the ante-mortem data only 3 of the 27 items are below 100 per cent, in the post-mortem data 7 of the 20 items are below 100 per cent.

A good idea of the relative anatomy of the two animals may be had by dividing the 20 items compared on the basis of actual units into seven groups, representing (1) body size, (2) organs of circulation, (3) organs of digestion and assimilation, (4) organs of elimination, (5) endocrine glands, (6) contents of alimentary canal, and (7) visceral fats.

In the body-size group are empty body weight and weight of hide. The average for this group is 191.1 per cent.

The circulation group includes the weight and the two circumferences of the heart. The percentages range from 120.6 to 101.1, and average 111.7 per cent.

The digestion and assimilation group includes the lengths and weights of the intestines and the total weight of empty stomachs. There are seven items in this group with percentages ranging from 124.5 to 47.6 and averaging 99.0 per cent. The three lengths of intestines range from 124.5 to 123.5 and average 124.1 per cent, the three weights of intestines range from 120.4 to 47.6 and average 80.7 per cent, and the total weight of empty stomachs is 78.8 per cent.

The elimination group consists of a single item, the weight of kidneys.

In the endocrine-gland group the percentages range from 313.0 for the weight of thyroid, to 111.9 for the weight of adrenals. The third item in this group, the spleen, has a percentage value of 187.6 and the average for the group is 204.2 per cent. On an average, this group shows a greater difference than any other in favor of the bull. The

two content items are the stomach and the intestines, with an average of 69.8 per cent.

The visceral fats (abdominal and thoracic) average 125.8 per cent.

The percentages in the body-size group would be expected to be similar to those for live weight and for empty body weight. A part of the difference in the weight of the hides of the cow and bull undoubtedly is explained by the fact that the portion of the hide which covered the udder of the cow was not included in the weight. Since the heart is a muscular organ serving all the body tissues, its size might also be expected to be more or less in proportion to the size of the animal. Furthermore, it is not surprising that the percentages for length of intestines approach those for live weight or empty body weight. The lower average percentage for weights of digestive organs may be at least partly due to the fact that the fat was more completely removed from the organs of the bull than from those of the cow. The reason for the low percentage for kidneys and the high average for the endocrine glands is not known. The percentages for contents of digestive tract and for visceral fat probably have comparatively little significance in this study.

When the post-mortem data are compared on the basis of the units per 100 pounds of empty body weight and grouped the same as on the other basis, it is seen that the percentages in the two series are related to each other in the proportion of approximately 173 to 100. The comments made in connection with the first series, therefore, apply also to the second.

SKELETAL STRUCTURE

The method employed in cleaning and mounting the skeleton of the cow was described in a previous publication.[7] The skeleton of the bull was prepared in the same manner.[8] The process used in cleaning the bones not only preserved the texture and all the delicate bony structures but prevented injury to the cartilage. The skeletons were cleaned and prepared with very little disarticulation, and mounted according to detailed measurements of the animals made before death.

Different views of the two skeletons and contours of the thoracic cavity and pelvic apertures are shown in Figures 6–12.

Detailed measurements of the two skeletons were made. As far as possible they corresponded to those taken on the living animal, but many additional ones were made. Obviously a measurement of the circumferences of barrel (fore chest, rear chest, and paunch) of the skeletons is impossible because at both the rear chest and paunch planes the ventral wall is missing. Contours, however, can be so drawn as to permit measurement with a greater degree of accuracy, as they represent the exact shape of the available portion of the skeleton at any desired point. Contours, prepared to show the differences in size and shape of the external outlines of the skeletons at the two planes used in measuring the fore chest and the paunch are presented in Figures 13 and 14.

The lower portion of the contours of the paunch can not be completed because the ribs do not meet. Areas of the contours at the

[7] SWETT, W. W., GRAVES, R. R., and MILLER, F. W. Op. cit.

[8] The skeleton work was done by the late C. E. Mirguet, an expert osteologist of the Smithsonian Institution, Washington, D. C.

paunch are obtained by connecting the lower extremities of each with a straight line and measuring the inclosed space. These areas, of course, are not comparable to those obtained ante mortem.

In addition to the external skeletal contours at the fore chest and at the paunch, inside contours were made of the anterior aperture of

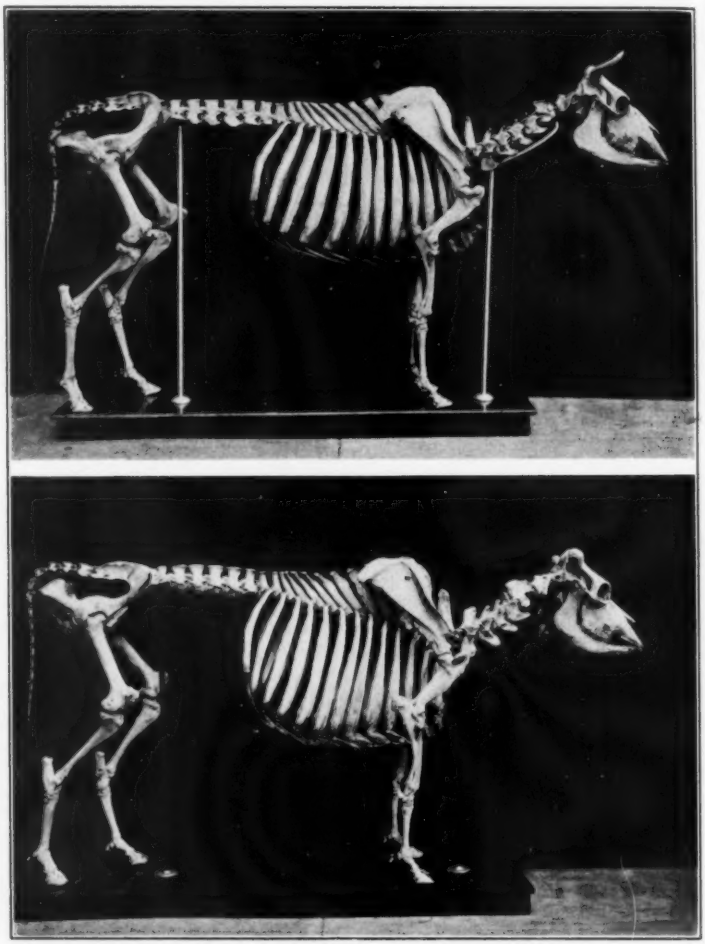

FIGURE 6.—Side view of skeletons (cow, above; bull, below)

the thoracic cage at the first rib, the thoracic cage at the seventh rib and at the thirteenth rib, and the pelvic aperture. The areas of all were measured, but only those for anterior aperture of thoracic cage and pelvic aperture are illustrated. (Figs. 8, 11, and 12.)

The skeletal measurements of the cow and the bull and the relation of the measurements of the bull to those of the cow expressed in

terms of percentage, together with a description of each measurement and the manner in which it was obtained, are presented in Table 4.

TABLE 4.—*Detailed skeletal measurements of cow and bull*

Item	Cow	Bull	Relation of bull's measurements to those of cow
	Centimeters	*Centimeters*	*Per cent*
Height at top of highest thoracic spinous process (withers)	120.00	119.50	99.6
Height at highest point on sacrum	121.25	121.25	100.0
Height at top of hip points	115.75	116.63	100.8
Height at top of pin bones	106.25	114.25	107.5
Length between bearing surfaces:			
Bones of thoracic limb—			
Scapula	37.00	39.00	105.4
Humerus	27.00	28.50	105.6
Radius	28.00	28.00	100.0
Metacarpus	20.50	18.50	90.2
Total	112.50	114.00	
Average	28.13	28.50	* 101.3
Length between bearing surfaces:			
Bones of pelvic limb—			
Femur	35.50	38.00	107.0
Tibia	33.50	34.00	101.5
Metatarsus	23.00	19.75	85.9
Total	92.00	91.75	
Average	30.67	30.58	* 99.7
Height at poll	129.00	122.75	95.2
Length, poll to third thoracic process	71.00	70.00	98.6
Length, third thoracic process to point on spine between hips	89.50	89.50	100.0
Length, point on spine between hips to rear of pin bones	47.00	48.00	102.1
Length, third thoracic process to rear of pin bones	136.50	137.50	100.7
Total length, poll to rear of pin bones	207.50	207.50	100.0
Sway of back	5.00	4.50	90.0
Width of forechest (outside, sixth rib)	33.25	32.25	97.0
Width of rearchest (outside, crossing center tenth rib)	55.00	53.00	96.4
Width of paunch (outside, crossing center thirteenth rib)	62.50	64.50	103.2
Depth of forechest (plane of sixth rib)	68.50	71.00	103.6
Maximum lateral width of thoracic cavity at anterior edge of each rib:			
1	9.50	9.75	102.6
2	11.50	11.00	95.7
3	15.50	14.00	90.3
4	19.50	18.00	92.3
5	23.50	22.50	95.7
6	27.50	26.50	96.4
7	33.00	32.50	98.5
8	41.50	40.00	96.4
9	49.00	47.00	95.9
10	55.00	53.50	97.3
11	60.00	59.50	99.2
12	62.00	62.50	100.8
13	62.50	65.00	104.0
Average	36.15	35.52	* 98.2
Vertical depth from ventral center of each thoracic vertebra to sternum or to a horizontal line across the lower extremity of the thoracic cage at the eighth to thirteenth vertebra:			
1	26.00	22.50	86.5
2	31.00	29.00	93.5
3	34.00	33.50	98.5
4	38.00	36.00	94.7
5	41.50	40.00	96.4
6	44.50	43.00	96.6
7	49.00	45.50	92.9
8	47.00	48.50	103.2
9	45.00	52.00	115.6
10	44.50	49.50	111.2
11	45.00	48.50	107.8
12	43.00	47.00	109.3
13	41.00	45.00	109.8
Average	40.73	41.54	* 102.0

* Based on average data of bull and of cow.

TABLE 4.—*Detailed skeletal measurements of cow and bull*—Continued

Item	Cow	Bull	Relation of bull's measurements to those of cow
	Centimeters	*Centimeters*	*Per cent*
Length, center of anterior edge of first rib to junction of thoracic and lumbar vertebrae (length of thoracic cavity)	76.00	76.50	100.7
Center axes, anterior aperture of thoracic cage:			
Lateral	8.00	8.00	100.0
Vertical	18.50	22.50	121.6
Contour or cross-section area of anterior aperture of thoracic cage	172.90	200.10	115.7
Contour area of thoracic cage (inside) at seventh rib	1,363.60	1,701.50	124.8
Contour area of thoracic cage (inside) at thirteenth rib	2,135.70	2,315.02	108.4
Contour area (outside) at plane used in measuring fore chest (sixth rib)	1,439.62	1,421.86	98.8
Contour area (outside) at plane used in measuring paunch (thirteenth rib)	2,396.23	2,429.48	101.4
Height at anterior dorsal point of sternum (ventral point of anterior aperture of thoracic cage)	72.00	62.00	86.1
Height at dorsal median posterior point on sternum between attachment of eighth ribs	52.50	47.75	91.0
Length of sternum between above points	40.00	39.50	98.8
Angle of sternum made with the horizontal	(b)		72.5
Length of thoracic cage measured on spine (cervical-thoracic to thoracic-lumbar junctions)	76.00	77.50	102.0
Average length of each thoracic vertebra (divide above length by 13)	5.85	5.96	101.9
Length of loin measured on spine (thoracic-lumbar to lumbar-sacral junctions)	41.00	38.50	93.9
Average length of each lumbar vertebra (divide above length by 6)	6.83	6.42	94.0
Length of spinous process of each thoracic vertebra:			
1	25.00	29.00	116.0
2	25.00	29.00	116.0
3	24.50	28.50	116.3
4	23.50	26.50	112.8
5	21.50	23.50	109.3
6	20.50	22.00	107.3
7	20.00	21.00	105.0
8	18.50	20.00	108.1
9	17.00	18.00	105.9
10	14.50	14.50	100.0
11	12.00	12.50	104.2
12	9.00	9.50	105.6
13	7.50	8.00	106.7
Average	18.35	20.15	a109.8
Length of spinous process of each lumbar vertebra:			
1	6.50	7.00	107.7
2	6.00	7.00	116.7
3	5.50	7.00	127.3
4	5.50	6.50	118.2
5	5.00	6.00	120.0
6	4.50	5.50	122.2
Average	5.50	6.50	a118.2
Width of each rib, 6 inches from its lowest ossified point (average of right and left):			
1	2.13	2.66	124.9
2	2.42	2.72	112.4
3	3.31	3.59	108.5
4	4.42	4.43	100.2
5	5.05	5.20	103.0
6	5.23	5.51	105.4
7	5.81	5.90	101.5
8	5.41	4.86	89.8
9	4.92	4.34	88.2
10	4.69	3.96	84.4
11	3.96	3.40	85.9
12	3.19	2.86	89.7
13	3.29	2.92	88.8
Total	53.83	52.35	
Average	4.14	4.03	a97.3

a Based on average data of bull and of cow.
b Cow, 29° 11′; bull, 21° 9′.

TABLE 4.—*Detailed skeletal measurements of cow and bull*—Continued

Item	Cow	Bull	Relation of bull's measurements to those of cow
Length of each rib, from vertebral attachment to lowest ossified point (average of right and left):	*Centimeters*	*Centimeters*	*Per cent*
1	27.00	30.33	112.3
2	32.00	35.00	109.4
3	36.00	39.25	109.0
4	39.25	43.00	109.6
5	43.75	48.00	109.7
6	48.00	52.50	109.4
7	52.50	56.50	107.6
8	55.25	57.88	104.8
9	55.25	57.75	104.5
10	55.25	57.25	103.6
11	54.00	56.00	103.7
12	52.25	54.17	103.7
13	48.50	49.13	101.3
Average	46.08	48.98	[a]106.3
Width of intercostal spaces (spaces between ribs) approximately 6 inches from lowest ossified point:			
1	1.89	2.89	152.9
2	2.15	2.91	135.3
3	1.96	2.34	119.4
4	1.80	2.53	140.6
5	1.80	2.09	116.1
6	2.76	1.92	69.6
7	1.30	1.51	116.2
8	3.75	2.44	65.1
9	4.51	3.74	82.9
10	4.78	4.34	90.8
11	4.92	3.49	70.9
12	5.07	3.35	66.1
Total	36.69	33.55	
Average	3.06	2.80	[a]91.4
Diameter of foramina of thoracic vertebrae (intervertebral and intravertebral):			
1	1.22	1.42	116.4
2	1.16	1.01	87.1
3	1.21	.88	72.7
4	1.05	1.11	105.7
5	.94	.98	104.3
6	.92	.95	103.3
7	.94	.95	101.1
8	.87	.96	110.3
9	.98	.94	95.9
10	1.10	.80	72.7
11	.84	.89	106.0
12	.74	.84	113.5
13	2.94	.96	32.7
Average	1.15	.98	[a]85.1
Diameter of foramina of lumbar vertebrae (intervertebral and intravertebral):			
1	2.20	1.08	49.1
2	[b]2.55	1.82	71.4
3	2.79	2.24	80.3
4	2.83	2.30	81.3
5	2.86	2.92	102.1
6	2.24	3.07	137.1
Average	2.58	2.24	[a]86.8
Length of loin, from center of hip to vertebral attachment of thirteenth rib	45.00	43.75	97.2
Width of loin:			
Third lumbar	29.00	30.25	104.3
Fourth lumbar	30.25	33.25	109.9
Average	29.63	31.75	[a]107.2

[a] Based on average data of bull and of cow.
[b] Opening for nerve branch that goes to udder.

TABLE 4.—*Detailed skeletal measurements of cow and bull*—Continued

Item	Cow	Bull	Relation of bull's measurements to those of cow
	Centimeters	*Centimeters*	*Per cent*
Width of hips (outside extremity)	46.50	47.50	102.2
Width of thurls (outside extremity)	40.50	41.00	101.2
Width of pin bones (outside extremity)	27.50	25.50	92.7
Length of rump, top of hip to top of pin bone	40.00	39.25	98.1
Angle of rump	(a)		25.4
Angle of floor of pelvis	(e)		102.5
Angle of pelvic aperture	(f)		79.3
Length of pelvic floor	17.50	20.50	117.1
Center axes of pelvic aperture:			
Anteroposterior (sacro-pubic)	25.00	21.00	84.0
Transverse	17.20	15.10	87.8
Contour area of pelvic aperture	384.30	273.15	71.1
Width between top points of pin bones	20.00	14.00	70.0
Width of pelvis immediately above center of acetabulum	17.75	13.75	77.5
Width of forehead	14.25	18.25	128.1
Width across eyes	20.75	24.25	116.9
Length from poll to tip of nose	47.00	47.50	101.1
Greatest depth at angle of jaw	26.00	25.50	98.1
Measurements of muzzle:			
Outside width of premaxillae (nasal processes)—			
At narrowest point corresponding to corner of mouth	7.66	8.58	112.0
Near anterior extremity, corresponding to greatest width of prehensile pad	8.28	9.69	117.0
Outside width of mandible (lower jaw)—			
At narrowest point, corresponding to corner of mouth	3.50	3.99	114.0
Near anterior extremity, corresponding to lateral limits of incisor teeth	7.74	8.48	109.6
Inside diameters of nasal passage—			
Lateral diameter	6.72	6.88	102.4
Depth from roof to floor	6.05	6.00	99.2
Measurements of bones of thoracic limb (scapula not included):			
Center of shaft of—			
Humerus—			
Circumference	14.00	16.50	117.9
Lateral diameter	3.92	4.35	111.0
Anterior-posterior diameter	4.87	5.85	120.1
Radius—			
Circumference	13.00	15.50	119.2
Lateral diameter	4.64	5.88	126.7
Anterior-posterior diameter	3.17	3.68	116.1
Metacarpus—			
Circumference	9.50	10.75	113.2
Lateral diameter	3.30	3.95	119.7
Anterior-posterior diameter	2.29	2.67	116.6
Average	6.52	7.68	* 117.8
Measurements of bones of pelvic limb:			
Center of shaft of—			
Femur—			
Circumference	12.50	14.00	112.0
Lateral diameter	3.53	4.05	114.7
Anterior-posterior diameter	4.30	5.03	117.0
Tibia—			
Circumference	11.50	13.25	115.2
Lateral diameter	4.10	4.95	120.7
Anterior-posterior diameter	2.93	3.57	121.8
Metatarsus—			
Circumference	9.50	10.50	110.5
Lateral diameter	2.78	3.27	117.6
Anterior-posterior diameter	2.90	3.08	106.2
Average	6.00	6.86	* 114.2

* Based on average data of bull and of cow.
[a] Cow, 13° 44'; bull, 3° 29'.
[e] Cow, 16° 36'; bull, 17° 1'.
[f] Cow, 38° 19'; bull, 30° 22'.

TABLE 4.—*Detailed skeletal measurements of cow and bull*—Continued

Item	Cow	Bull	Relation of bull's measurements to those of cow
Measurements of cervical vertebrae:	*Centimeters*	*Centimeters*	*Per cent*
At greatest width—			
1 (atlas)	15.30	20.60	134.64
2 (axis)	10.40	13.70	131.73
3	11.10	15.30	137.84
4	11.40	16.00	140.35
5	11.05	15.20	137.56
6	10.90	14.30	131.19
7	11.55	14.30	123.81
Average	11.67	15.63	[a] 133.90
At greatest depth—			
1 (atlas)	9.68	10.08	104.13
2 (axis)	13.73	15.33	111.65
3	11.70	14.23	121.62
4	12.80	14.60	114.06
5	13.88	17.15	123.56
6	18.20	20.65	113.46
7	20.23	24.60	121.60
Average	14.32	16.66	[a] 116.38

[a] Based on average data of bull and of cow.

The skeletons of the cow and bull were almost the same in height. The percentages of 100.8 for height at hips and 107.5 for height at pin bones signify that the slope of rump was less for the bull than for

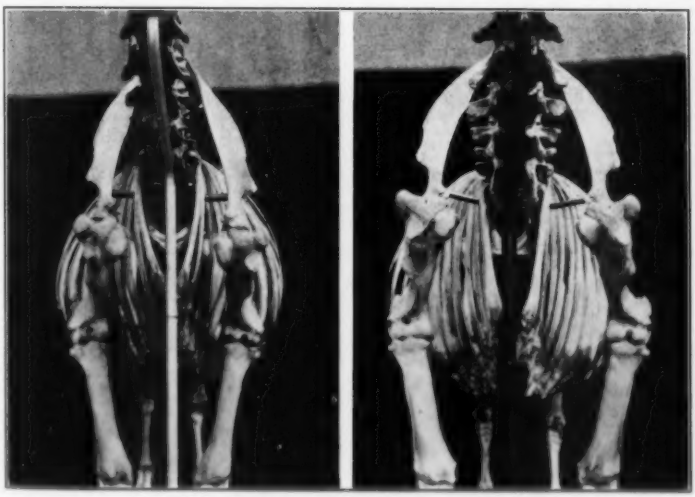

FIGURE 7.—Front view of skeletons (cow, left; bull, right)

the cow. In view of the similarity in height of body, one would expect the length of the bones of the thoracic and pelvic limbs of the bull to be similar to those of the cow, and Table 4 indicates that such

TABLE 4.—*Detailed skeletal measurements of cow and bull*—Continued

Item	Cow	Bull	Relation of bull's measurements to those of cow
	Centimeters	*Centimeters*	*Per cent*
Length, center of anterior edge of first rib to junction of thoracic and lumbar vertebrae (length of thoracic cavity)	76.00	76.50	100.7
Center axes, anterior aperture of thoracic cage:			
Lateral	8.00	8.00	100.0
Vertical	18.50	22.50	121.6
Contour or cross-section area of anterior aperture of thoracic cage	172.90	200.10	115.7
Contour area of thoracic cage (inside) at seventh rib	1,363.60	1,701.50	124.8
Contour area of thoracic cage (inside) at thirteenth rib	2,135.70	2,315.02	108.4
Contour area (outside) at plane used in measuring fore chest (sixth rib)	1,439.62	1,421.86	98.8
Contour area (outside) at plane used in measuring paunch (thirteenth rib)	2,396.23	2,429.48	101.4
Height at anterior dorsal point of sternum (ventral point of anterior aperture of thoracic cage)	72.00	62.00	86.1
Height at dorsal median posterior point on sternum between attachment of eighth ribs	52.50	47.75	91.0
Length of sternum between above points	40.00	39.50	98.8
Angle of sternum made with the horizontal	(b)		72.5
Length of thoracic cage measured on spine (cervical-thoracic to thoracic-lumbar junctions)	76.00	77.50	102.0
Average length of each thoracic vertebra (divide above length by 13)	5.85	5.96	101.9
Length of loin measured on spine (thoracic-lumbar to lumbar-sacral junctions)	41.00	38.50	93.9
Average length of each lumbar vertebra (divide above length by 6)	6.83	6.42	94.0
Length of spinous process of each thoracic vertebra:			
1	25.00	29.00	116.0
2	25.00	29.00	116.0
3	24.50	28.50	116.3
4	23.50	26.50	112.8
5	21.50	23.50	109.3
6	20.50	22.00	107.3
7	20.00	21.00	105.0
8	18.50	20.00	108.1
9	17.00	18.00	105.9
10	14.50	14.50	100.0
11	12.00	12.50	104.2
12	9.00	9.50	105.6
13	7.50	8.00	106.7
Average	18.35	20.15	a109.8
Length of spinous process of each lumbar vertebra:			
1	6.50	7.00	107.7
2	6.00	7.00	116.7
3	5.50	7.00	127.3
4	5.50	6.50	118.2
5	5.00	6.00	120.0
6	4.50	5.50	122.2
Average	5.50	6.50	a118.2
Width of each rib, 6 inches from its lowest ossified point (average of right and left):			
1	2.13	2.66	124.9
2	2.42	2.72	112.4
3	3.31	3.59	108.5
4	4.42	4.43	100.2
5	5.05	5.20	103.0
6	5.23	5.51	105.4
7	5.81	5.90	101.5
8	5.41	4.86	89.8
9	4.92	4.34	88.2
10	4.69	3.96	84.4
11	3.96	3.40	85.9
12	3.19	2.86	89.7
13	3.29	2.92	88.8
Total	53.83	52.35	
Average	4.14	4.03	a97.3

a Based on average data of bull and of cow.
b Cow, 29° 11′; bull, 21° 9′.

TABLE 4.—*Detailed skeletal measurements of cow and bull*—Continued

Item	Cow	Bull	Relation of bull's measurements to those of cow
Length of each rib, from vertebral attachment to lowest ossified point (average of right and left):	*Centimeters*	*Centimeters*	*Per cent*
1	27.00	30.33	112.3
2	32.00	35.00	109.4
3	36.00	39.25	109.0
4	39.25	43.00	109.6
5	43.75	48.00	109.7
6	48.00	52.50	109.4
7	52.50	56.50	107.6
8	55.25	57.88	104.8
9	55.25	57.75	104.5
10	55.25	57.25	103.6
11	54.00	56.00	103.7
12	52.25	54.17	103.7
13	48.50	49.13	101.3
Average	46.08	48.98	[a]106.3
Width of intercostal spaces (spaces between ribs) approximately 6 inches from lowest ossified point:			
1	1.89	2.89	152.9
2	2.15	2.91	135.3
3	1.96	2.34	119.4
4	1.80	2.53	140.6
5	1.80	2.09	116.1
6	2.76	1.92	69.6
7	1.30	1.51	116.2
8	3.75	2.44	65.1
9	4.51	3.74	82.9
10	4.78	4.34	90.8
11	4.92	3.49	70.9
12	5.07	3.35	66.1
Total	36.69	33.55	
Average	3.06	2.80	[a]91.4
Diameter of foramina of thoracic vertebrae (intervertebral and intravertebral):			
1	1.22	1.42	116.4
2	1.16	1.01	87.1
3	1.21	.88	72.7
4	1.05	1.11	105.7
5	.94	.98	104.3
6	.92	.95	103.3
7	.94	.95	101.1
8	.87	.96	110.3
9	.98	.94	95.9
10	1.10	.80	72.7
11	.84	.89	106.0
12	.74	.84	113.5
13	2.94	.96	32.7
Average	1.15	.98	[a]85.1
Diameter of foramina of lumbar vertebrae (intervertebral and intravertebral):			
1	2.20	1.08	49.1
2	[b]2.55	1.82	71.4
3	2.79	2.24	80.3
4	2.83	2.30	81.3
5	2.86	2.92	102.1
6	2.24	3.07	137.1
Average	2.58	2.24	[a]86.8
Length of loin, from center of hip to vertebral attachment of thirteenth rib	45.00	43.75	97.2
Width of loin:			
Third lumbar	29.00	30.25	104.3
Fourth lumbar	30.25	33.25	109.9
Average	29.63	31.75	[a]107.2

[a] Based on average data of bull and of cow.
[b] Opening for nerve branch that goes to udder.

TABLE 4.—*Detailed skeletal measurements of cow and bull*—Continued

Item	Cow	Bull	Relation of bull's measurements to those of cow
	Centimeters	*Centimeters*	*Per cent*
Width of hips (outside extremity)	46.50	47.50	102.2
Width of thurls (outside extremity)	40.50	41.00	101.2
Width of pin bones (outside extremity)	27.50	25.50	92.7
Length of rump, top of hip to top of pin bone	40.00	39.25	98.1
Angle of rump	(d)		25.4
Angle of floor of pelvis	(e)		102.5
Angle of pelvic aperture	(f)		79.3
Length of pelvic floor	17.50	20.50	117.1
Center axes of pelvic aperture:			
Anteroposterior (sacro-pubic)	25.00	21.00	84.0
Transverse	17.20	15.10	87.8
Contour area of pelvic aperture	384.30	273.15	71.1
Width between top points of pin bones	20.00	14.00	70.0
Width of pelvis immediately above center of acetabulum	17.75	13.75	77.5
Width of forehead	14.25	18.25	128.1
Width across eyes	20.75	24.25	116.9
Length from poll to tip of nose	47.00	47.50	101.1
Greatest depth at angle of jaw	26.00	25.50	98.1
Measurements of muzzle:			
Outside width of premaxillae (nasal processes)—			
At narrowest point corresponding to corner of mouth	7.66	8.58	112.0
Near anterior extremity, corresponding to greatest width of prehensile pad	8.28	9.69	117.0
Outside width of mandible (lower jaw)—			
At narrowest point, corresponding to corner of mouth	3.50	3.99	114.0
Near anterior extremity, corresponding to lateral limits of incisor teeth	7.74	8.48	109.6
Inside diameters of nasal passage—			
Lateral diameter	6.72	6.88	102.4
Depth from roof to floor	6.05	6.00	99.2
Measurements of bones of thoracic limb (scapula not included):			
Center of shaft of—			
Humerus—			
Circumference	14.00	16.50	117.9
Lateral diameter	3.92	4.35	111.0
Anterior-posterior diameter	4.87	5.85	120.1
Radius—			
Circumference	13.00	15.50	119.2
Lateral diameter	4.64	5.88	126.7
Anterior-posterior diameter	3.17	3.68	116.1
Metacarpus—			
Circumference	9.50	10.75	113.2
Lateral diameter	3.30	3.95	119.7
Anterior-posterior diameter	2.29	2.67	116.6
Average	6.52	7.68	*117.8
Measurements of bones of pelvic limb:			
Center of shaft of—			
Femur—			
Circumference	12.50	14.00	112.0
Lateral diameter	3.53	4.05	114.7
Anterior-posterior diameter	4.30	5.03	117.0
Tibia—			
Circumference	11.50	13.25	115.2
Lateral diameter	4.10	4.95	120.7
Anterior-posterior diameter	2.93	3.57	121.8
Metatarsus—			
Circumference	9.50	10.50	110.5
Lateral diameter	2.78	3.27	*117.6
Anterior-posterior diameter	2.90	3.08	106.2
Average	6.00	6.86	*114.2

* Based on average data of bull and of cow.
d Cow, 13° 44′; bull, 3° 29′.
e Cow, 16° 36′; bull, 17° 1′.
f Cow, 38° 19′; bull, 30° 22′.

TABLE 4.—*Detailed skeletal measurements of cow and bull*—Continued

Item	Cow	Bull	Relation of bull's measurements to those of cow
Measurements of cervical vertebrae:	*Centimeters*	*Centimeters*	*Per cent*
At greatest width—			
1 (atlas)	15.30	20.60	134.64
2 (axis)	10.40	13.70	131.73
3	11.10	15.30	137.84
4	11.40	16.00	140.35
5	11.05	15.20	137.56
6	10.90	14.30	131.19
7	11.55	14.30	123.81
Average	11.67	15.63	[a] 133.90
At greatest depth—			
1 (atlas)	9.68	10.08	104.13
2 (axis)	13.73	15.33	111.65
3	11.70	14.23	121.62
4	12.80	14.60	114.06
5	13.88	17.15	123.56
6	18.20	20.65	113.46
7	20.23	24.60	121.60
Average	14.32	16.66	[a] 116.38

[a] Based on average data of bull and of cow.

The skeletons of the cow and bull were almost the same in height. The percentages of 100.8 for height at hips and 107.5 for height at pin bones signify that the slope of rump was less for the bull than for

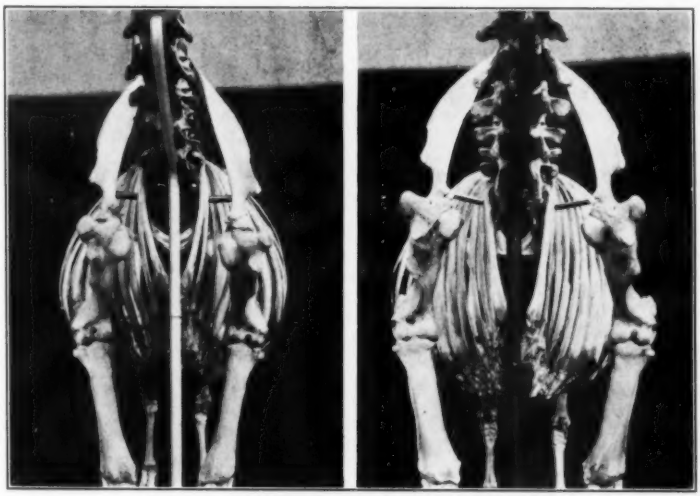

FIGURE 7.—Front view of skeletons (cow, left; bull, right)

the cow. In view of the similarity in height of body, one would expect the length of the bones of the thoracic and pelvic limbs of the bull to be similar to those of the cow, and Table 4 indicates that such

is the case. The total length of the four bones of the thoracic limb is 101.3 per cent as great for the bull as for the cow. A similar relationship is found in the length of the bones of the pelvic limb, the percentage being 99.7. The total length of the fore and the rear legs of the bull is almost identical with that of the cow, but the upper units are distinctly longer and the lower units distinctly shorter in the bull. The advantage of this is that it gives the bull additional strength for defense and for carrying his weight during copulation. The height at poll is 6.25 cm less for the bull than for the cow, but since this is determined almost entirely by the angle at which the thoracic and cervical portions of the spinal column are joined in assembling the skeleton, little significance is attached to this difference.

The length from poll to third thoracic process (withers) is probably the least significant measurement in this group because of the extent to which it is affected by the height and position of the head and neck. However, the average of the five percentages representing general body lengths is 100.3, which shows that the measurements of body length are even more similar for the two skeletons than the measurements of height.

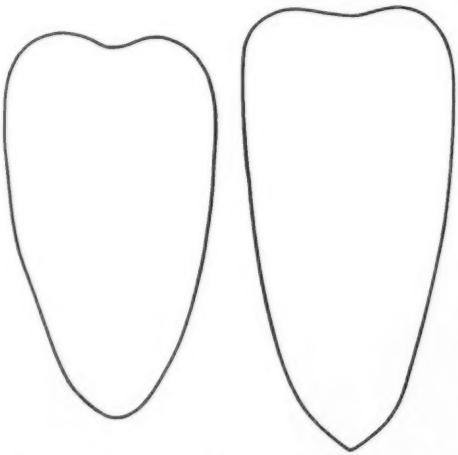

FIGURE 8.—Contours of anterior aperture of thoracic cavity (cow, left; bull, right)

For two animals varying so greatly in size there is surprising similarity in the widths of the fore chest, rear chest, and paunch. Not one of these measurements differs by more than 2 cm (less than 1 inch), and the relation of width of bull to width of cow at these three points averages 98.9 per cent. The maximum lateral width of the thoracic cavity taken at the anterior edge of each rib is less for the bull at 10 of the 13 ribs, but on an average the two animals are strikingly similar.

At the fifth, sixth, and seventh ribs, which represent the region of the plane used in measuring the fore chest, the percentages average 96.9; at the tenth rib, the plane of the rear chest, the percentage is 97.3; and at the thirteenth rib, the plane at which the paunch measurements were taken, the percentage is 104.0. The lowest percentage is for the third rib and the highest percentage is for the thirteenth. Ante-mortem measurements of the chest are not possible at the plane represented by the lowest percentage because of the position of the scapula and humerus. The generally progressive increase in percentage from the third to the thirteenth rib and the ratio of the widths of paunch to chest show definitely that the lateral wedge of the skeleton was greater for the bull than for the cow, whereas the ante-mortem wedge shape was less.

The outside depth of fore chest at the sixth rib was 103.6 per cent as great for the bull as for the cow. Obviously a depth at the tenth and thirteenth ribs which would be comparable to the ante-mortem measure-

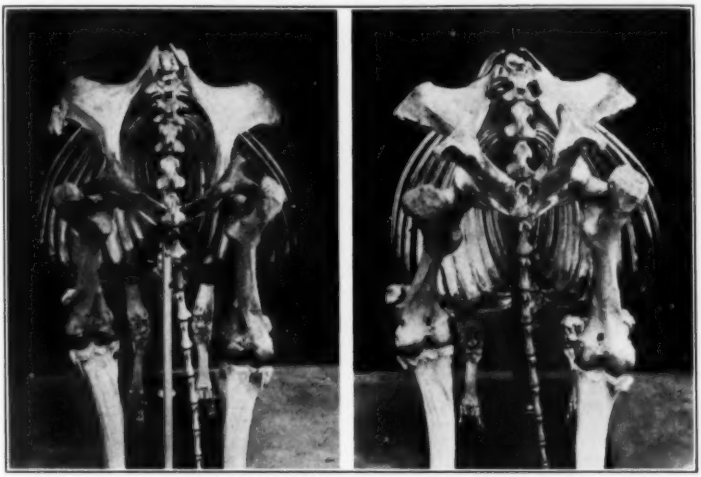

FIGURE 9.—Rear view of skeletons (cow, left; bull, right)

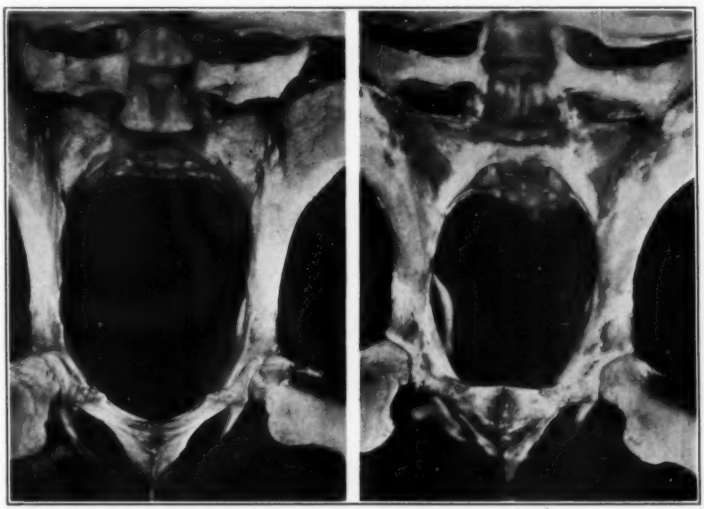

FIGURE 10.—View of anterior pelvic aperture in each skeleton, taken to the same scale from below and in front, with camera approximately perpendicular to the rim of the pelvis (cow, left; bull, right)

ment at the same plane, could not be obtained. The two skeletons are, however, compared in depth by measuring, in a vertical plane, the depth from the ventral center of each thoracic vertebra to the dorsal

surface of the sternum at each vertebra from the first to the seventh, inclusive, and to a horizontal line across the points forming the lower extremity of the thoracic cage at each vertebra from the eighth to the thirteenth, inclusive. At each of the first seven vertebrae the bull is shallower than the cow. For the next six vertebrae the depth is in each case greater for the bull. On an average, the depths are similar for the two skeletons. The fact that the bull is 3.5 cm shallower than the cow (86.5 per cent) at the first thoracic vertebra and 4.0 cm deeper (109.8 per cent) at the thirteenth thoracic vertebra, together with the fact that all depths from the first to the seventh vertebrae are less for the bull (average 94.2 per cent), whereas those from the eighth to the thirteenth vertebrae are all greater (average 109.5 per cent), shows a decidedly greater vertical wedge for the bull than for the cow. Although the ante-mortem and post-mortem measurements for depth of body are not comparable because much of the

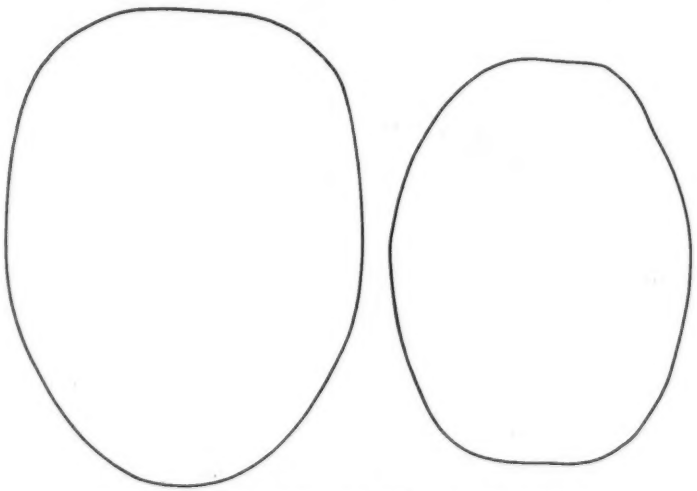

FIGURE 11.—Contours of the anterior pelvic aperture (cow, left; bull, right)

ante-mortem depth in the abdominal region is nonskeletal, the bull in each instance appears to have a greater vertical wedge shape than the cow. (Fig. 6.)

In length of thoracic cavity the two skeletons are almost the same whether measured from center of anterior edge of first rib to thoracic-lumbar junction, or from cervical-thoracic to thoracic-lumbar junctions. The lateral axis of the anterior aperture of the thoracic cage is exactly the same in both skeletons, but the vertical axis is 4.0 cm greater for the bull. Contour areas of the inside of the thoracic cage at the anterior aperture (fig. 8), at the plane of the seventh rib and at the plane of the thirteenth rib, average 116.3 per cent as great for the bull as for the cow. The outside contour areas at the sixth and thirteenth ribs, the planes used in obtaining the ante-mortem measurements of the fore chest and paunch, are, respectively, 98.8 and 101.4 per cent as great for the bull as for the cow. (Figs. 13 and 14.)

The sternum of the bull is much lower in front, considerably lower in the rear, of almost the same length, and is set at an angle of 21° 9′ as compared with 29° 11′ for the cow. (Fig. 6.)

The bull is considerably shorter than the cow in the region of the loin. Although the thoracic vertebrae average 0.11 cm longer, the lumbar vertebrae average 0.41 cm shorter for the bull than for the cow. The fact that the lumbar portion of the vertebral column is actually 2.5 cm shorter in a bull than in a cow weighing 573 pounds less is worthy of note. The additional length of loin in the cow may serve the purpose of providing more room for the development and delivery of the fetus. The shorter loin in the bull may give him added strength for his activities in fighting and in copulating.

In every instance the thoracic spinous processes are of equal or greater length in the bull, averaging 9.8 per cent longer than in the cow. The greatest difference is in the spinous processes attached to the anterior vertebrae, the first 6 of which average 113.0; whereas the 6 posterior ones average 105.1, as compared to 108.7 per cent for the entire 13. (Figs. 6 and 15.) Every one of the lumbar spinous processes also is longer, averaging 1.0 cm, or 18.2 per cent greater in the bull. (Figs. 6 and 16.)

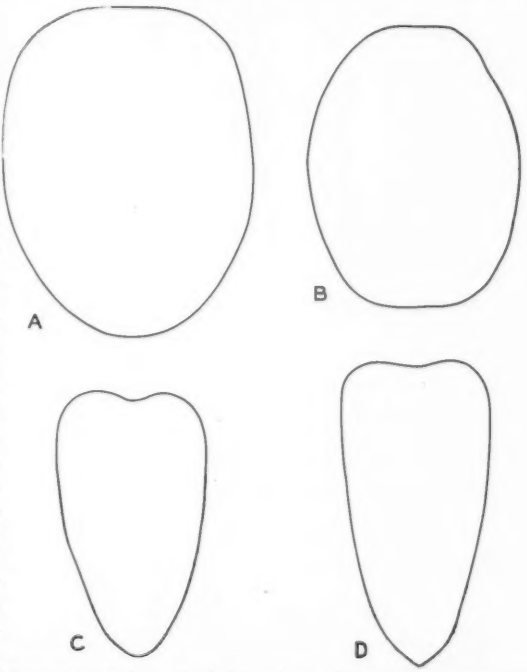

FIGURE 12.—Contours of anterior pelvic aperture and anterior aperture of thoracic cavity, shown together to illustrate relative size of each; A, Anterior pelvic aperture of cow; B, anterior pelvic aperture of bull; C, anterior aperture of thoracic cavity of cow; D, anterior aperture of thoracic cavity of bull

The ribs differ considerably in width, length, and position. (Fig. 6.) They average 0.11 cm less in width for the bull. The anterior ribs of the bull are wider, but the posterior ribs are narrower than those of the cow, the percentages for width averaging 109.1 for the 6 anterior ribs, but only 87.8 for the 6 posterior ribs, whereas the entire 13 average 98.7. The bull's ribs average 2.9 cm longer than those of the cow. The greatest differences in length also are found

in the anterior ribs, the first 6 averaging 109.9 per cent, but the 6 posterior ribs only 103.6 per cent. There are, of course, only 12 intercostal spaces on each side, and they average 0.26 cm narrower in the bull. In length of thoracic spinous processes, width of ribs, and length of ribs the relation of bull to cow is markedly different in the anterior portion of the thoracic cavity from what it is in the posterior. In width of intercostal spaces this difference is even more striking, the percentages averaging 122.3 for the 6 anterior spaces,

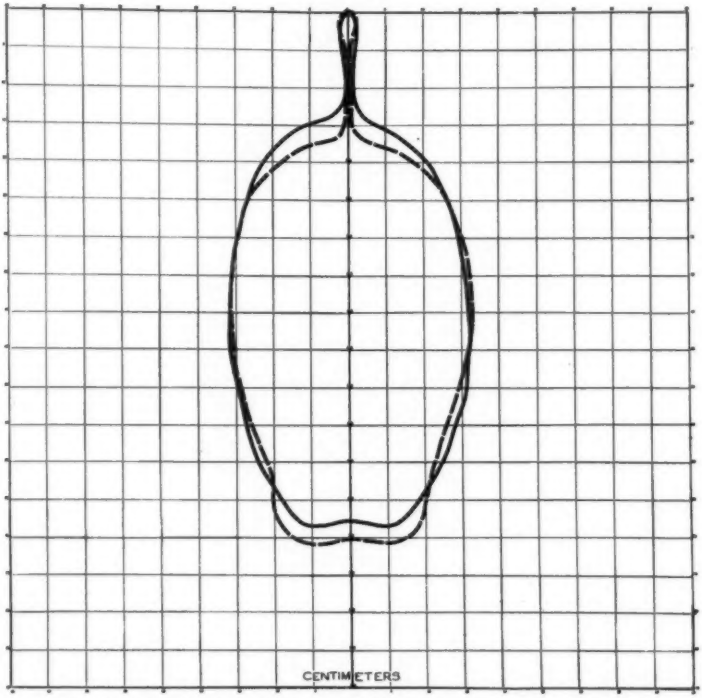

FIGURE 13.—External contours of fore chest of skeletons (cow, solid line; bull, broken line)

but only 82.0 for the 6 posterior spaces, as compared to 102.2 for the 12 spaces.

The significance of openness of conformation, as an indication of size of intervertebral and intravertebral foramina and of the freedom of passage of nerves from the spinal cord, was discussed in a previous publication.[9] It was pointed out that intravertebral foramina are more numerous than intervertebral foramina, and consequently that the width of spaces between vertebrae would not be expected to be of great importance as an indication of freedom of passage of nerves. There is some indication that intervertebral foramina are relatively more numerous in the lumbar than in the thoracic portions. The method of measuring the foramina was the same as that outlined in

[9] SWETT, W. W., GRAVES, R. R., and MILLER, F. W. Op. cit.

the previous publication. Some of the foramina were elongated and somewhat irregular in shape, but the measurement recorded as the diameter is the greatest transverse dimension measurable. Some vertebrae had both intervertebral and intravertebral foramina. Some were divided by cartilage or bone into two parts. Whenever a vertebra had two foramina or one divided into two parts, both were measured and the total of the two diameters was recorded. (Figs. 15 and 16.)

The thoracic foramina average 0.17 cm less in diameter, or only 85.1 per cent as much for the bull. In eight of the cases recorded

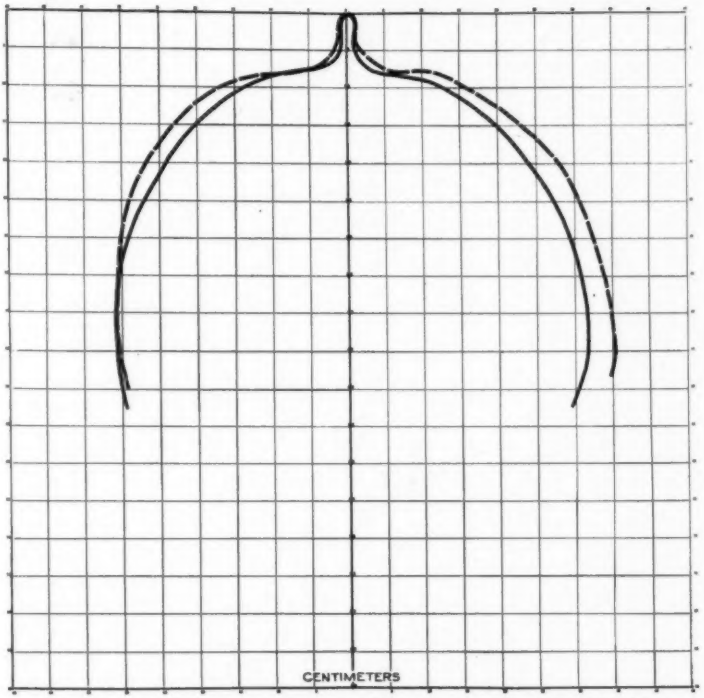

FIGURE 14.—External contours of paunch of skeletons (cow, solid line; bull, broken line)

the measurement was greater for the bull, and in five it was less. The average of the percentages for the 6 anterior vertebrae is 98.3; for the 6 posterior ones it is 88.5; and for the entire group of 13 it is 94.0. On an average the lumbar foramina are 0.34 cm less in diameter, or 86.8 per cent as large in the bull.

Each of the percentages for lumbar foramina is greater than that for the next anterior vertebra. The reason for this steady increase in percentages is not understood. It was pointed out in comparing the dairy cow with the beef cow, that the nerves which lead to the udder leave the spinal cord and pass through foramina between the second and third lumbar vertebrae. The foramen at this location is only 71.4 per cent as large in the bull—a difference in diameter of 0.73 cm. The significance of size of foramina appears to be still in doubt.

The length of loin, measured from the center of the face of the hip to the attachment of the thirteenth rib, is less for the bull, but the width of loin as measured at the third and fourth lumbar vertebrae is considerably greater. The widths of hips, thurls, and pin bones are, respectively, 1.0 cm greater, 0.5 cm greater, and 2.0 cm less for the bull.

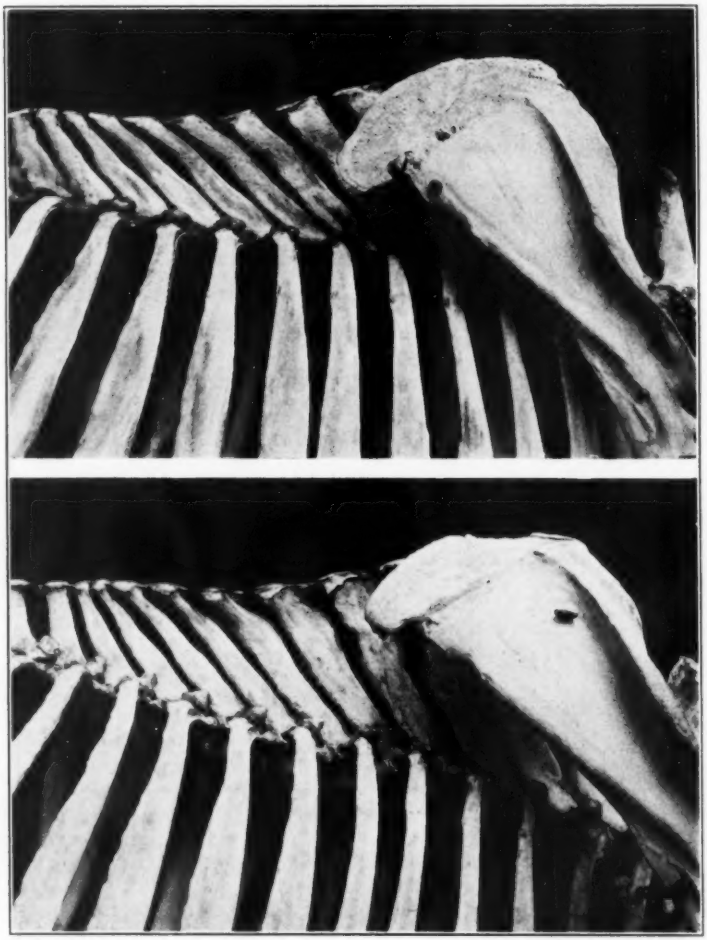

FIGURE 15.—Thoracic vertebrae, ribs, and spinous processes, showing foramina (cow, above; bull, below)

This difference in width at pin bones, which is rather high for so small a measurement, is an indication of the narrowness of the pelvis in the male as compared with that of the female. The length of rump of the two skeletons is almost the same. The angle or slope of rump is greater for the cow, the angle of the pelvic floor is almost the same for

both skeletons, and the angle of pelvic aperture is greater for the cow. Although the skeletons were assembled according to the measurements taken on the living animals, the possibility that any of these angles might have been affected by the final assembly is recognized. The

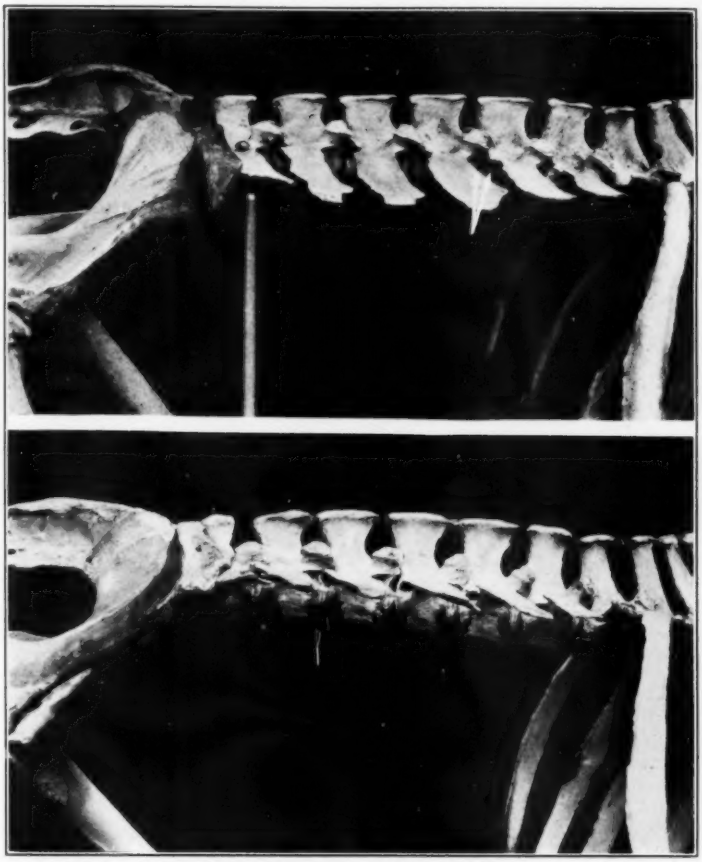

FIGURE 16.—Lumbar vertebrae and spinous processes showing foramina (cow, above; bull, below). Arrows indicate foramina that permit passage of nerve which supposedly innervates the mammary gland

length of pelvic floor is 3.0 cm greater in the bull, a difference of 17.1 per cent, which is relatively high.

The difference in size and shape of pelvis is one of the most striking found in this study. (Figs. 10 and 11.) In the previous publication [10] the data for lateral and longitudinal axes of the anterior pelvic aperture were interchanged through error. In this discussion the error is corrected and the terms "anteroposterior (sacro-pubic)" and "transverse" are used to indicate the axes measured. Both are much smaller in the bull. The contour of the anterior pelvic aperture of each

[10] SWETT, W. W., GRAVES, R. R., and MILLER, F. W. Op. cit.

skeleton was drawn and its area measured. As a result of the redrawing, the area of the cow is slightly different from that previously published. In this comparison the area of the anterior pelvic aperture of the bull is only 71.1 per cent as great as that of the cow. The area of the anterior pelvic aperture of the bull is only 66.3 per cent of what it would be if it were in proportion to the ante-mortem width of hips, thurls, pin bones, and loin; only 69.6 per cent as great as it would be if it were in proportion to the skeletal width of hips, thurls, pin bones, and loin; and only 41.1 per cent of what it would be if it were in proportion to the total animal structure or empty body weights of the two animals. This is illustrated in another way by Figure 12, which shows the contours of the anterior apertures of the pelvis and of the thoracic cavity of each skeleton. The area of the anterior pelvic aperture of the bull is only 61.4 per cent as great as it would be if it

FIGURE 17.—Front view of the skulls (cow, left; bull, right)

were in proportion to the areas of the anterior aperture of the thoracic cavity. The posterior aperture also—in fact the entire pelvic cavity—is distinctly less roomy in the bull. The width between the top of the pin bones and the width above the acetabulum are both very much less in the bull. The greater roominess of the pelvic cavity in the female is one of the most striking differences between the two animals and nicely illustrates the provision of nature for the delivery of the fetus.

In a group of 10 measurements of the head, 8 are larger for the bull. The two that are smaller for the bull are greatest depth at angle of jaw and depth of nasal passage, but the percentages for these measurements indicate that the differences are of little significance. The greatest individual differences in head measurements are, in the order named, width of forehead, outside width of nasal processes, and width across eyes. (Fig. 17.) The length from poll to tip of nose

(the only head length measured) is nearly the same for the two animals (101.1 per cent); the widths of head average 114.3; and the depths of head average 98.7 per cent. The greatest differences in head measurements are, therefore, in width.

Figure 6 shows little difference in the heads as viewed from the side, but indicates a marked difference in heaviness of cervical vertebrae. The cervical vertebrae of the bull are greater, averaging 3.96 cm more in width and 2.34 cm more in depth. The outstanding difference between the measurements of the head of the cow and of the bull appears to be the difference in width.

The circumference and the lateral and anterior-posterior diameters of the bones of the thoracic limb (except the scapula, which was not measured), and of the pelvic limb, are in every instance greater for the bull.

INTERRELATIONS OF ANTE-MORTEM, POST-MORTEM, AND SKELETAL-STRUCTURE DATA

The ante-mortem and skeletal-structure data which appear to be representative of body size, or which might be considered as having an association with the functions of circulation and respiration or of digestion and assimilation, have been grouped in a manner similar to that followed in discussing the post-mortem data. The percentages showing the relation of the bull's measurements to those of the cow, for the ante-mortem, post-mortem, and skeletal-structure data, are assembled in Table 5, according to the functional grouping outlined.

In the data for body size the seven ante-mortem items are much greater for the bull. The first (live weight) and the last two (volume of barrel and body-surface area) are largely dependent on the muscular development and fleshing of the animal. They average 144.3 per cent. The other four, which are more significant of body dimensions, average only 103.7 per cent. The two post-mortem items average 191.1 per cent, but since empty body weight is almost entirely dependent, and weight of hide is to some extent dependent, on fleshing, such a high percentage is not surprising. The four skeletal measurements average 100.9 per cent. It is apparent, therefore, that the differences in the body-size group are due almost entirely to the degree of fleshing of the animal.

In the circulation and respiration group also, the ante-mortem items, which are measurements of the fore chest, are much greater for the bull. In this group also, the width, circumference, and especially the contour-area measurements, are affected materially by the fleshing of the animal. As the lung weights were not compared, the three post-mortem items refer to circulation but not to respiration. They are somewhat greater for the bull. The four skeletal-structure items are only slightly greater for the bull, indicating again the effect of fleshing on the ante-mortem differences.

In the digestion and assimilation group also the ante-mortem items are much greater for the bull. The seven post-mortem items average 99.0 per cent, and the three skeletal-structure items average 104.3 per cent.

The average percentages showing the relation of bull to cow indicate that the bull's organs of circulation were relatively large in proportion to the skeletal development in the fore chest, while the organs of digestion and assimilation were relatively small in proportion to the skeletal measurements of the paunch.

TABLE 5.—*Ante-mortem, post-mortem, and skeletal-structure data grouped on the basis of their association with body size, circulation and respiration, and digestion and assimilation*

Type of data	Data for body size		Data for circulation and respiration		Data for digestion and assimilation	
	Item	Relation of bull's measurements to those of cow	Item	Relation of bull's measurements to those of cow	Item	Relation of bull's measurements to those of cow
		Per cent		*Per cent*		*Per cent*
Ante-mortem	Live weight	161.8	Depth, fore chest	102.8	Depth, paunch	112.4
	Height at withers	99.9	Width, fore chest	138.2	Width, paunch	122.2
	Width of hips	104.7	Circumference, fore chest	117.6	Circumference, paunch	116.5
	Length, withers to pin bones	101.1	Contour area, fore chest	146.8	Contour area, paunch	141.3
	Length, poll to mouth (tape)	108.9				
	Volume of barrel	149.0				
	Body surface area	122.0				
	Average	121.1		126.4		123.1
Post-mortem	Empty body weight	173.0	Weight of heart	120.6	Weight, small intestine	120.4
	Weight of hide	209.1	Circumference of heart (base)	101.1	Weight, large intestine	47.6
			Circumference of heart (apex)	113.5	Total weight, intestines	74.2
					Length, small intestine	124.5
					Length, large intestine	123.5
					Total length, intestines	124.3
					Total weight, stomachs	78.8
	Average	191.1		111.7		99.0
Skeletal structure.	Height at withers	99.6	Depth, fore chest	103.6	Width, paunch	103.2
	Width of hips	102.2	Width, fore chest	97.0	Contour area, paunch (inside thoracic cage at thirteenth rib)	103.4
	Length, withers to pin bones	100.7	Contour area chest (inside, seventh rib)	124.8	Contour area, paunch (outside thirteenth rib)	101.4
	Length poll to tip of nose (caliper)	101.1	Contour area fore chest (outside sixth rib)	98.8		
	Average	100.9		106.1		104.3

The ante-mortem averages for the three groups (121.1, 126.4, and 123.1 per cent) average 123.0 per cent, and are very similar; the post-mortem averages, aside from those of the body-size group, which is dependent to a very high degree on condition and fleshing, are considerably lower (111.7 and 99.0 per cent); and the skeletal-structure items also are lower (100.9, 106.1, and 104.3 per cent). Considered on any basis, the data emphasize the similarity of the two animals from the standpoint of body dimensions, internal anatomy, and skeletal structure, and show that the differences which existed were to a very great extent due to differences in the muscular development and fleshing of the animals.

SUMMARY

EXTERNAL CONFORMATION OF LIVING ANIMAL

Although the bull was 61.8 per cent heavier than the cow, his body lengths and heights were, on an average, not more than 2 per cent greater.

The bull's depths averaged 7.4 per cent, and his widths and circumferences averaged, respectively, 17.5 and 17.8 per cent greater.

On an average, the depths, widths, and circumferences of barrel (fore chest, rear chest, and paunch measurements) were 7.4, 26.4, and 15.5 per cent greater for the bull.

In the entire group of 25 conformation measurements, only 3 were less for the bull, and the average was 10.7 per cent greater for the bull.

The averages for each group of conformation measurements show that the bull was larger, but the differences in measurements do not approach the difference in live weight.

The bull was 46.8 per cent greater in contour area of fore chest and 41.3 per cent greater in contour area of paunch. The proportion of the total area above the vertical mid-point of the contours of the fore chest and of the paunch were almost identical for the two animals. The distribution of the area of the paunch indicated for both animals a deep but "slab-sided" body.

The cow and bull were similar in respect to slope of rump.

The thoracic and abdominal indexes indicate that the cow was deep and narrow and the bull relatively wide in the fore chest but that both were similar at the paunch.

The bull was 49.0 per cent larger in volume of barrel and 22.0 per cent larger in body-surface area.

In legginess very little difference between the two animals was found.

The wedge shape of the bull was greater than that of the cow from the standpoint of depth, but from the standpoint of width, circumference, and contour area it was less.

The circumference of shin bone or metacarpus as measured in the living animal indicated considerably greater heaviness of bone in the bull.

The greatest conformation differences were found in widths and circumferences. The nine conformation measurements showing the greatest difference between cow and bull were all for width or circumference. Only moderate differences were noted between the depths of body of the two animals. The smallest differences were in heights and lengths, which indicates that the relative "scale" of the two animals was almost the same.

INTERNAL ANATOMY

The empty body weight of the bull was 560.8 pounds, or 73.0 per cent greater than that of the cow. The corresponding ante-mortem differences of 573 pounds and 61.8 per cent are similar.

The total lengths of intestines for the cow and bull were, respectively, 166.50 and 206.96 feet. Although this difference is considerable, the length recorded for the cow is at least 30 feet above the minimum, and that for the bull is about 35 feet below the maximum, recorded in a post-mortem study of a large number of animals, now in progress.

Retention of blood in the lungs of the cow prevented the determination of her lung weight. That of the bull was 8.70 pounds, which on

the basis of data obtained from a large number of cows, indicates that the weight of lungs for each 100 pounds of empty body weight was decidedly low.

In weight and in circumference over the apex, the heart of the bull was considerably greater than that of the cow. In circumference near the base the hearts were almost the same. When compared with the weight of heart of the cow used in this study, or with the average for a large number of cows on which post-mortem data are available, the weight of heart of the bull for each 100 pounds of empty body weight is low.

The 20 post-mortem weights and measurements compared were 125.1 per cent as great for the bull as for the cow. Thirteen of these were above 100 per cent and averaged 154.2 per cent. Of the 7 items below 100 per cent, only the 2 which represented total weight of empty stomachs and weight of kidneys were comparable or significant; the 2 items which represented contents of digestive tract are affected by conditions of management; weight of thoracic fat is probably of little significance; and the other two items, which represented weight of intestines, might have been affected by the writers' inability to remove all the fat. The average of the 13 items above 100 per cent and the 2 below 100 per cent that may be significant, was 144.8 per cent.

The relation of bull to cow appears to have been 191.1 per cent for the post-mortem items directly associated with body size, 111.7 per cent for those pertaining to circulation, 99.0 per cent for the organs of digestion and assimilation, 87.8 per cent for the kidneys, 204.2 per cent for the endocrine glands studied, and 125.8 per cent for the visceral fats.

Except for the weights of kidneys, total stomachs, and total intestines, the weights and measurements of the organs and body parts were rather consistently greater for the bull.

From the standpoint of units of weight or measurement for each 100 pounds of empty body weight, only four items were greater for the bull. These are weight of thyroid, weight of hide, which is directly associated with body size, weight of spleen, and weight of abdominal fat, which probably is of little significance. The average for the 19 items is 70.9 per cent. The average for the four items above 100 is 129.0 per cent. It appears, therefore, that aside from some of the endocrine glands, the difference in size of organs was not in proportion to the difference in the empty body weight of the two animals.

The only organs found to be proportionately larger in the bull were the thyroid and the spleen.

SKELETAL STRUCTURE

The skeletal heights were almost the same for the bull as for the cow. This should have been the case since the skeletons were assembled on the basis of ante-mortem height measurements, which were nearly the same for both animals.

The total length of the leg bones was almost the same for both animals. In both the thoracic and pelvic limbs, however, the upper (dorsal) bones were longer in the bull, and the lower (ventral) bones were longer in the cow.

The skeletal body lengths of the two animals were almost identical.

Outside widths, taken as nearly as possible at the planes used in measuring the ante-mortem widths of fore chest, rear chest, and

paunch, were strikingly similar for the two animals. In no instance was the difference greater than 2 cm.

The widths of thoracic cavity taken at the anterior edge of each rib were similar, but averaged slightly less for the bull than for the cow. They do, however, indicate a somewhat greater lateral wedge for the bull, which is the reverse of the relation shown by the ante-mortem measurements.

On an average, the inside depths of the thoracic cavity of the bull differed from those of the cow by less than 1 cm. They were, however, less in front and greater in the rear, showing a considerably greater vertical wedge for the bull. This is in agreement with the ante-mortem data.

The length of thoracic cavity and the average length of thoracic vertebrae were almost the same for the two animals.

Although the average widths, average depths, and the length of the thoracic cavity of the cow and bull were very similar, the inside cross section or contour areas measured were distinctly greater for the bull. The outside contour areas at the fore chest and at the paunch, however, were almost the same for both animals.

The sternum of the bull was much lower in front, considerably lower in the rear, almost the same in length, and slightly more nearly level than the sternum of the cow.

The loin was considerably shorter and wider in the bull.

The dorsal spinous processes, both thoracic and lumbar, were distinctly longer in the bull, but very little difference in their position was noted. The greatest differences in thoracic processes were found in those attached to the anterior vertebrae and may have had some relation to the "crest" in the bull.

The lateral processes attached to the lumbar vertebrae were nearly horizontal in the bull, whereas those in the cow inclined downward.

The anterior ribs of the bull were wider and the posterior ribs were narrower, but on an average they were nearly the same for both animals.

The length of every one of the ribs was greater for the bull, but the largest relative differences were found in connection with the anterior ribs.

The average width of the spaces between ribs was slightly greater in the bull; but the anterior ones were very much greater, and the posterior ones very much less in the bull.

Although there was a great deal of variation in individual vertebrae, both the thoracic and lumbar foramina were on an average distinctly smaller in the bull. The one that is supposed to permit passage of the nerve which in the cow innervates the udder, was only 71.4 per cent as large in the bull as in the cow. The significance of the size of foramina appears to be speculative.

The pelvis of the bull was strikingly different from that of the cow in many respects, although the width of hips and thurls and the length of rump of the two animals were nearly the same. The slope of the rump was considerably less in the bull, the angle of the pelvic floor was about the same in both animals, and the angle of the anterior pelvic aperture was somewhat less in the bull. The floor of the pelvis was longer in the bull. The axes of the anterior pelvic aperture were both distinctly less in the bull, and its contour area was only 71.1 per cent as great in the bull as in the cow. The width between the top points of the pin bones, and the width of pelvis above the acetabulum were both

very much less in the bull. The entire pelvic cavity was distinctly less roomy in the bull.

The width of head was distinctly greater in the bull, but the other head measurements differed only slightly.

The cervical vertebrae were noticeably larger in the bull, particularly in width.

The similarity in measurements of height and of length of the entire skeleton, as well as its parts, indicates that both skeletons were almost the same in "scale."

The circumference and the lateral and anterior-posterior diameters of the leg bones, except the scapula, which was not measured, were in every instance greater in the bull. A relatively greater heaviness of bone in the bull was indicated.

A comparison of large numbers of cow and bull skeletons would be desirable but impracticable. The data obtained in this study are presented to show the differences found between two skeletons, and it is not to be inferred that the same differences would necessarily be found between skeletons of all cows and bulls.

CONCLUSIONS

The external conformation of the bull differed considerably from that of the cow. The most marked differences noted were in widths and circumferences of the body and in general heaviness in the anterior parts. In body depths the animals were only moderately different, and in the measurements which indicate "scale" they were almost the same.

The apparent differences in the conformation of the cow and bull are due largely to (1) the "crest" of the bull, which is partly skeletal but mostly muscular; (2) the low front chest development in the bull, which gets its appearance partly from the heavy muscular development, and partly from the low position of the anterior end of the sternum bone, but largely from the abundance of loose skin that extends from the throat to the brisket; and (3) the fact that the head of the bull, although similar in length and depth to that of the cow, is much broader. Any tendency for the bull to appear light in the flank is due in part to his relatively heavy muscular development in the front quarters, and to the fact that he does not, like the cow, have an udder to carry out his underline on a downward slope.

Although many of the bull's internal organs were actually larger than those of the cow in units of weight or measurement, only two of them were proportionately as large as in the cow when considered on the basis of total animal structure or empty body weight. The differences in size of internal organs do not appear to be sufficiently great to indicate significant differences in functional ability.

In skeletal structure the cow and bull were very similar. The greatest differences appear in the cervical vertebrae and in the size and shape of the pelvis. The first gives the bull the necessary strength to defend himself; the second is undoubtedly a provision of nature to enable the cow to give birth to her young.

The cow and bull were surprisingly similar in some of their body dimensions, and in their internal anatomy and skeletal structure. The differences which did exist were to a very great extent due to differences in muscular development and fleshing.

EFFICIENCY FACTORS AND THEIR USE IN DETERMINING OPTIMUM FERTILIZER RATIOS[1]

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INTRODUCTION

The conventional methods of interpreting the results of field experiments with fertilizers may not prove to be entirely satisfactory under all circumstances. For example, in a single experiment involving a large number of fertilizer ratios, a situation may arise wherein yields having no statistically significant differences are derived from several treatments which appear to have only a remote resemblance to each other. Under such conditions it is virtually impossible to determine the optimum fertilizer ratio, and the investigator is compelled either to guess or to have recourse to supplementary experiments of various types. Economic interpretations based on fertilizer costs are possible, of course, and are frequently used, but it is doubtful whether their use is justified in experiments in which the primary object is to determine the optimum ratios.

The experiment discussed in this paper, because of the large number of treatments involved, proved to be extremely difficult to interpret. Of the 63 fertilizer treatments included in the work, the 10 highest ranking ratios proved to be not only quite diverse, but also to have a maximum difference in increased yields over adjacent checks of only 0.323 ± 0.162 ton, or 20.85 ± 9.4 per cent. (Table 1.) Neither one of these differences is statistically significant, and yet these 10 treatments are quite dissimilar as to ratio. In this case supplementary experiments were conducted in several sections of Illinois on many different types of soils, with the result that the optimum ratios were found to be included among the 10 mentioned.

Conducted in this way, fertilizer experiments become unduly burdensome and expensive, because of the large number of treatments which must be included in the supplementary work. The question naturally arises, Is it not possible to submit the results of the original experiment to a more intensive and critical analysis than is usually given them? Would such an analysis narrow the range of treatments to be considered and lead to the determination of the optimum ratio without recourse to supplementary tests? The purpose of this article is to outline a method by which this may be done and to illustrate it by analyzing an extensive fertilizer experiment.

[1] Received for publication Nov. 9, 1931; issued November, 1932.

TABLE 1.—*Mean increases in sweet-corn yields per acre in fertilized plots over respective adjacent checks*

Treatment	Edible ears				Green fodder			
	Tons increase over check	Dev. P. E.	Student's odds	Percentage increase over check	Tons increase over check	Dev. P. E.	Student's odds	Percentage increase over check
001	−0.193±0.058	3.3	33:1	−8.98+2.7	−0.452±0.265	1.7	6:1	−12.24± 7.2
002	.030± .034	0.9	2:1	1.63±1.6	.162± .108	1.5	5:1	5.07± 3.4
004	.066± .058	1.1	3:1	3.58±3.2	−.078± .109	.7	2:1	−2.44± 3.5
010	.397± .084	4.7	179:1	22.63±4.8	.432± .110	3.9	73:1	15.64± 4.0
011	.244± .070	3.5	43:1	13.91±4.0	.303± .104	2.9	22:1	10.97± 3.8
012	.338± .095	3.6	46:1	17.99±5.0	.410± .131	3.1	28:1	13.58± 4.4
014	.519± .102	5.1	276:1	27.62±5.4	1.188± .152	7.8	4,999:1	39.36± 5.0
020	.224± .060	3.7	57:1	10.02±2.7	.393± .139	2.8	19:1	11.46± 4.1
021	.419± .094	4.4	132:1	18.75±4.3	.795± .137	5.8	610:1	23.18± 4.0
022	.409± .101	4.0	83:1	18.52±4.6	.873± .180	4.8	198:1	25.62± 5.3
024	.457± .072	6.3	989:1	21.36±3.4	1.150± .168	6.8	1,866:1	33.74± 5.0
040	.363± .076	4.8	198:1	19.45±4.0	.004± .105	.04	<1:1	1.26±31.5
041	.673± .086	7.8	4,999:1	37.41±4.8	.940± .152	6.2	908:1	32.29± 5.2
042	.683± .082	8.3	>9,999:1	37.28±4.5	.939± .162	5.8	610:1	33.02± 5.7
044	.776± .115	6.7	1,799:1	43.50±6.5	1.322± .144	9.2	>9,999:1	47.62± 5.2
100	.087± .082	1.1	3:1	5.51±5.0	.252± .212	1.2	3:1	9.74± 8.1
101	−.232± .124	1.9	7:1	−12.41±6.5	.061± .226	.3	1:1	2.09± 7.0
102	.037± .095	.4	1:1	1.89±4.7	.849± .123	6.9	1,932:1	28.22± 4.1
104	−.094± .080	1.2	3:1	−4.70±3.9	.242± .170	1.4	4:1	7.70± 5.5
110	.241± .053	4.6	151:1	12.62±2.7	.430± .106	4.1	83:1	14.71± 3.6
111	.178± .068	2.6	16:1	9.07±3.5	−.056± .087	.6	2:1	−1.77± 3.0
112	.598± .092	6.5	1,221:1	34.73±5.3	1.145± .144	8.0	4,999:1	42.34± 5.3
114	.612± .080	7.6	3,332:1	38.54±5.1	.920± .098	9.4	>9,999:1	35.91± 3.8
120	.526± .070	7.5	3,332:1	28.93±3.9	.422± .100	4.2	99:1	13.91± 3.3
121	.626± .086	7.3	3,332:1	34.47±4.7	.825± .177	4.7	169:1	26.66± 5.7
122	.776± .142	5.5	400:1	44.47±8.1	1.056± .200	5.3	339:1	34.30± 6.5
124	.532± .090	5.9	666:1	31.11±5.3	1.057± .185	5.7	553:1	36.24± 6.4
140	.594± .121	4.9	224:1	30.12±6.1	.733± .155	4.7	179:1	23.09± 4.9
141	.651± .125	5.2	323:1	32.76±6.3	1.100± .178	6.2	948:1	35.46± 5.7
142	.797± .115	6.9	1,932:1	40.11±5.8	1.503± .138	10.9	>9,999:1	48.45± 4.4
144	.971± .134	7.2	3,332:1	55.58±7.7	1.919± .243	7.9	4,999:1	68.36± 8.6
200	−.051± .038	1.3	2:1	−2.91±2.2	−.125± .076	1.6	5:1	−4.86± 3.0
201	−.147± .038	3.9	66:1	−7.17±1.8	−.168± .088	1.9	7:1	−5.25± 2.8
202	−.054± .097	.6	2:1	−2.91±4.8	−.006± .177	.03	<1:1	−.20± 6.6
204	.092± .105	.9	2:1	5.32±5.9	.656± .159	4.1	88:1	24.66± 6.0
210	.091± .100	.9	2:1	4.96±5.5	.029± .144	0.2	1:1	1.01± 5.0
211	.264± .092	2.9	21:1	14.45±5.0	.338± .105	3.2	31:1	10.04± 3.1
212	.545± .106	5.1	293:1	31.95±6.3	.577± .185	3.1	28:1	19.79± 6.4
214	.447± .093	4.8	198:1	25.10±5.2	.898± .132	6.8	1,799:1	29.81± 4.4
220	.543± .083	6.5	1,332:1	31.50±4.8	.227± .133	1.7	6:1	7.74± 4.6
221	.593± .098	6.1	811:1	31.92±5.2	.809± .138	5.8	638:1	27.78± 4.8
222	.598± .102	5.8	666:1	29.93±5.2	1.129± .136	8.3	>9,999:1	38.69± 4.7
224	.371± .130	2.8	17:1	16.50±5.9	1.430± .180	8.0	2,499:1	42.88± 5.4
240	.648± .091	7.1	1,499:1	29.16±4.1	1.241± .175	7.1	1,499:1	38.06± 5.4
241	.571± .107	5.3	354:1	26.20±4.8	1.068± .194	5.5	431:1	33.20± 6.0
242	.563± .160	3.5	43:1	25.66±7.3	1.398± .228	6.1	860:1	40.71± 6.7
244	.622± .070	8.9	9,999:1	27.27±3.1	1.648± .165	10.0	>9,999:1	52.05± 5.2
400	−.107± .057	1.9	6:1	−4.85±2.6	−.053± .084	.6	2:1	−1.58± 2.6
401	.327± .063	5.2	195:1	17.38±3.3	.506± .132	3.8	48:1	16.63± 4.4
402	−.060± .086	.7	2:1	−3.01±4.3	.188± .139	1.4	4:1	6.26± 4.5
404	−.050± .086	.6	2:1	−2.24±3.7	−.089± .169	.5	2:1	−2.37± 4.7
410	.287+ .095	3.0	25:1	14.81±4.9	−.053± .302	.2	<1:1	−1.55± 7.8
411	.318± .103	3.1	27:1	16.06±5.1	.595± .137	4.3	109:1	18.05± 4.2
412	.250± .067	3.7	57:1	12.14±3.3	.693± .180	3.8	63:1	19.45± 5.1
414	.572± .130	4.4	123:1	30.12±7.0	1.007± .201	5.0	241:1	29.89± 6.0
420	.736± .083	8.9	>9,999:1	38.98±4.4	.946± .183	5.2	308:1	31.56± 6.1
421	.422± .131	3.2	31:1	22.35±7.0	.409± .184	2.2	10:1	13.65± 6.2
422	.587± .058	10.1	>9,999:1	32.04±3.2	.995± .127	7.8	4,999:1	35.15± 4.5
424	.651± .046	14.2	>9,999:1	35.53±2.5	1.155± .132	8.8	>9,999:1	40.80± 4.6
440	.360± .092	3.9	68:1	15.73±4.0	.959± .176	5.4	400:1	26.32± 4.9
441	.571± .063	9.1	>9,999:1	24.94±2.7	1.270± .216	5.9	666:1	34.85± 5.9
442	.334± .080	4.2	99:1	13.13±3.1	.940± .115	8.2	4,999:1	21.74± 2.6
444	.144± .074	1.9	7:1	5.89±3.1	.822± .152	5.4	369:1	19.01± 3.5

METHODS OF CRITICAL ANALYSIS

In even the most elementary types of field experiments it is customary to apply nitrogen, phosphorus, and potash singly, any two together, or all three together in various proportions. As a rule, the only use which is made of the results thus secured is to show the effect of omitting one or two of the elements. This is of considerable value

in determining the soil requirements, but no advantage is taken of the fact that salts applied singly or by twos afford a means of determining indirectly the effects of fertilizer combinations if the proper comparisons are made.

A very simple theoretical experiment will serve as an example. Assuming that the experiment consists of applications in equal amounts of 2–12–6, 0–12–6, 2–0–6, and 2–12–0, the appropriate subtractions of the yields will show the effect of each element. Thus 0–12–6 subtracted from 2–12–6, 2–0–6 subtracted from 2–12–6, and 2–12–0 subtracted from 2–12–6 will show the effect of adding nitrogen, phosphorus, and potash, respectively. In this paper the differences thus obtained are called "efficiency factors," and the respective differences are the nitrogen-efficiency factor, the phosphorus efficiency factor, and the potash efficiency factor. These factors, however, have but little value in an experiment of only four plots; but if two more plots are added and the same amounts of 4–12–6 and 8–12–6 are used, the efficiency factors can then be utilized. Thus by subtracting the yields from treatment 0–12–6 from those of 2–12–6, 4–12–6, and 8–12–6, the respective efficiencies of 2, 4, and 8 per cent nitrogen can be determined. The relationship is very simple, and the efficiency of the nitrogen applications varies directly with the yield, since the yield of 0–12–6 is a constant. The relationship, however, may be much more complex. Let it be assumed that four treatments of a different type are added to the original experiment, as for instance, 0–18–6, 0–24–6, 2–18–6, and 2–24–6, and that the nitrogen efficiency of 2–12–6, 2–18–6, and 2–24–6 is desired. This may be obtained by subtracting from the preceding the treatments 0–12–6, 0–18–6, and 0–24–6, respectively. Should the efficiency of nitrogen increase in the order in which the treatments appear, it would be concluded that successively larger dosages of phosphorus tend to increase the efficiency of nitrogen. This is an indirect effect due to phosphorus which can not be determined by direct inspection of the yields for each treatment. This method can be extended to include all three nutrient elements and, moreover, proves to be useful in analyzing plot data.

The problem analyzed in this paper is based on a 6-year accumulation of sweet-corn yields from 389 separate plots in a fertilizer-rotation series at Urbana, Ill. The means in Table 1 have been calculated from approximately 1,200 separate plot records and constitute the problem in the solution of which the efficiency-factor method will be applied.

LOCATION AND PLAN OF THE EXPERIMENTS

The experiment was laid out in four 10-acre fields at Urbana, Ill. Three of the fields had been planted for an indefinite period to the field corn and oats rotation typical of central Illinois, but the fourth field was in bluegrass pasture for four years prior to the experiment. Neither limestone nor commercial fertilizers of any kind had ever been applied to any of the fields. Soil-acidity tests of several types showed a limestone requirement of 3 tons, and this was applied at the beginning of the experiment. The soils in these fields vary very widely, but the predominating one is a dark semimature type having a noncalcareous subsoil.

The four fields were first laid out in 1922 and 1923 on the basis of a 4-year rotation consisting of wheat or oats, red clover, followed by

two crops of sweet corn grown for canning, which was a typical rotation at that time. Fertilizer was applied to each of the two sweet-corn crops, the yields of which are the only ones presented in this paper.

The field methods used throughout the work were as accurate as could be devised. All the fertilizers were broadcast by hand and harrowed in within 24 hours of planting. The corn was planted rather thickly by hand in check rows 42 by 42 inches and later thinned to three stalks per hill. The variety of sweet corn used was Country Gentlemen, bred at the station.

The fertilizer treatments consisted of a modification of those recommended by Spillman (*8*).[2] The following arbitrary dosages were selected as the basis of application:

7.5, 15, and 30 pounds nitrogen per acre as sodium nitrate.
32, 64, and 128 pounds P_2O_5 per acre as 16 per cent superphosphate.
25, 50, and 100 pounds K_2O per acre as potassium chloride.

These treatments are called respectively, single, double, and quadruple, and will frequently be referred to in the text as such. Whereas Spillman (*8*) recommended a single and double treatment, this plan was elaborated by adding a quadruple treatment.

These quantities of plant nutrients were applied in all possible mathematical combinations. Excluding the zero dosage for all 3 elements (checks), there are 63 combinations. An advantage of this layout is the large number of possible direct comparisons. There are 48 possible comparisons for determining the effects of any one of the three single elements, 16 where any two vary, and 4 where all three vary.

For the sake of brevity the treatments will be presented in the form of the amount applied in the conventional N–P–K sequence. Thus the treatment 124 means a single dosage of nitrogen (7.5 pounds per acre), a double dosage of phosphorus (64 pounds P_2O_5 per acre), and a quadruple dosage of potash (100 pounds K_2O per acre). In the case of 024, the dosage is the same as 124 except that the nitrogen is omitted. A complete list of the treatments follows:

000	020	100	120	200	220	400	420
001	021	101	121	201	221	401	421
002	022	102	122	202	222	402	422
004	024	104	124	204	224	404	424
010	040	110	140	210	240	410	440
011	041	111	141	211	241	411	441
012	042	112	142	212	242	412	442
014	044	114	144	214	244	414	444

The plots were so laid out in each field that every third one was a check. No maintenance fertilizer treatment was applied to any of the checks during the period covered by this report. Nevertheless, the check yields have been maintained reasonably well by the use of limestone and clover. The treated plots differ from the checks in receiving only the fertilizer in addition to limestone and clover. The practice has been to remove from all plots, including checks, one cutting of clover, one small-grain crop, including the straw, and only the green ears from the two sweet-corn crops. The green fodder was cut, weighed, and then returned to the plot from which it came.

[2] Reference is made by number (italic) to Literature Cited, p. 704.

All the subsequent data have been computed on an acre basis from the plots, each of which is 28 by 77 feet, or 0.04949+ acre, net size after a single border row had been removed around the plot. The gross size is 31.5 by 80.5 feet, or 0.058213 acre. The distance between the net plots with borders removed is 15 feet in each field.

All the fertilizer salts used in this experiment were chemically analyzed, and the amounts applied to each plot were calculated on this basis.

EXPERIMENTAL METHODS

The harvesting of sweet corn in the edible green stage presents problems peculiar to this crop. Botanically immature when snapped, sweet corn is accordingly subject to considerable variation in total weight of ears due to increases in the amount of food material stored and the total percentage of moisture present at different stages. Wide variations in maturity resulting from the differential effect of fertilizers prevent any possibility of harvesting the plots simultaneously without incurring a large and decisive experimental error due to differences in weight. On the basis of the work of Appleman and Eaton (*3*) the author experimented in 1922 with a method of silk counting in order to determine the probable date of harvest for each plot. Appleman (*2*) and Culpepper and Magoon (*4*) in extensive experiments with sweet corn, have shown that maturity can be determined with reasonable accuracy by means of silk counts. The accuracy of the method with respect to field corn has been demonstrated by Myers (*7*) who has shown that there is a high degree of correlation between silk counts and dry maturity. Although there is reason to believe that silk counting in sweet corn is a much less reliable index of maturity than in field corn, owing to the multiplicity of suckers and shoots in the former, no other field method of predicting maturity is known at present which will answer the same purpose.

The weights given in the subsequent tables are for edible green corn harvested as nearly as possible at a stage when not more than 5 per cent of the ears by weight were showing slight denting. The weights are those of sorted corn, the culls being omitted.

The weights of green fodder were obtained by weighing the stalks immediately after the green corn was harvested.

No corrections for soil variations have been made beyond comparing the yield of each treatment with that of the adjacent check.

STATISTICAL METHODS

Each treatment has been paired with its respective adjacent check and the significance of the mean differences in yield determined by the use of Student's method (*1*, *5*, *6*). The odds appear in Table 1.

The probable errors of the mean increases in yields expressed both as tons and percentages have been calculated according to the formula $\frac{0.6745\ S.\ D.}{\sqrt{n}}$. The probable errors of certain factors appearing in Tables 2 to 13, inclusive, have also been determined, and the methods of calculation will be discussed along with the derivation of these factors. Deviations which are 3.2 or more times their probable errors are considered statistically significant. Student's odds which are 30:1 or more are likewise considered significant.

EXPERIMENTAL RESULTS

The mean increases or decreases in yield from the fertilized plots as compared with the yields from the respective adjacent checks, together with the odds and the respective percentages, are shown in Table 1. These means have been calculated from 12 annual crops over the 6-year period, 1923 to 1928, inclusive. The data in Tables 2 to 7 have been computed from Table 1, but the intermediate steps are not shown.

The results are discussed from two standpoints, the first in terms of increased yields expressed as percentages and taken directly from Table 1, and the second as efficiency factors. The term "efficiency factor" as used in this paper means the increase in the percentage yield due to one of the three major nutrient elements designated. Each efficiency factor has been calculated from Table 1 by means of direct comparisons between appropriate fertilizer combinations. For example, in treatment 144 it is possible to determine for edible green ears the efficiency factors for all three elements, as follows:

Nitrogen efficiency factor:	
Per cent increase in yield, treatment 144	55.58 ± 7.7
Per cent increase in yield, treatment 044	43.50 ± 6.5
Increase due to nitrogen, or N efficiency factor	12.08 ± 10.1
Phosphorus efficiency factor:	
Per cent increase in yield, treatment 144	55.58 ± 7.7
Per cent increase in yield, treatment 104	-4.70 ± 3.9
Increase due to phosphorus, or P efficiency factor	60.28 ± 8.6
Potash efficiency factor:	
Per cent increase in yield, treatment 144	55.58 ± 7.7
Per cent increase in yield, treatment 140	30.12 ± 6.1
Increase due to potash, or K efficiency factor	25.46 ± 9.8

The probable errors of the efficiency factors have been calculated from the formula $\sqrt{a^2+b^2}$ where a and b represent the probable errors of the two percentages used in the subtraction. The correlation is assumed to equal zero.

Because of the mathematical relation existing between the fertilizer treatments, a very large number of comparisons may be made. In order to avoid confusion, a uniform method of analysis is used in Tables 2 to 7, which consists of determining the efficiency factors for individual treatments in the appropriate 2-element series and comparing them by means of curves (figs. 1, A, to 12, A, and 1, C, to 12, C) derived from Tables 2 to 7. Comparisons must also be made, of course, in the 3-element series, that is, the complete fertilizers, but as there are three dosages of the third element in each case, three additional sets of curves would be necessary. In order to avoid this, the 0, 1, 2, and 4 dosages of the third or quiescent element, have been averaged in Tables 2 to 7 and these means compared in curves. (Figs. 1, B, to 12, B, and 1, D, to 12, D.) In order to indicate the fact that a given treatment is a mean of this type, the letter X is substituted for the third or quiescent element. Thus 12X indicates that this treatment is the average of 120, 121, 122, and 124.

The probable errors of these "X" treatments are determined in each instance by means of the formula $\frac{1}{N}\sqrt{a^2+b^2+c^2\ldots n^2}$, in which

a, *b*, *c*, etc., indicate the probable errors of single deviations, and *N* the number of deviations, which is four in each case.

This system of averaging is open to certain objections, the principal one being that comparisons between individual treatments may lead to conclusions which differ from those in this paper. The same criticism is applicable, however, whenever any attempt is made to compare the trends between single determinations and means.

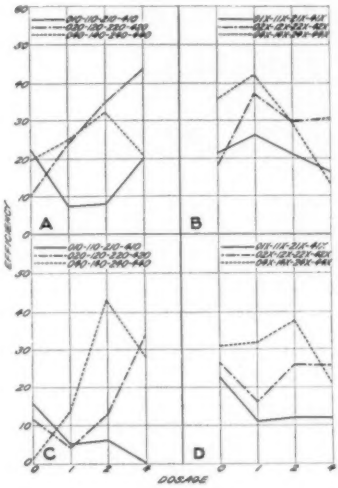

FIGURE 1.—The effect of successive increments of nitrogen on the efficiency of phosphorus, both with and without potash; results for two elements shown in A and C, for three elements in B and D, for edible ears in A and B, and for green fodder in C and D

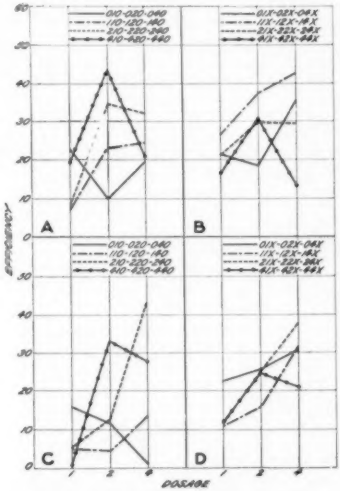

FIGURE 2.—The effect of successive increments of phosphorus on its efficiency in nitrogen-phosphorus combinations, both with and without potash; results for two elements shown in A and C, for three elements in B and D, for edible ears in A and B, and for green fodder in C and D

EFFECT OF NITROGEN ON THE EFFICIENCY OF PHOSPHORUS

The effect of nitrogen on the efficiency of phosphorus is shown in Table 2 and Figures 1 and 2. The efficiency factors for both edible ears and green fodder are given.

The efficiency factors for edible ears (Table 2 and figs. 1, A, and 1, B) will be discussed first, comparisons being made in the order of increasing nitrogen with phosphorus constant, as follows:

010–110–210–410.
020–120–220–420.
040–140–240–440.

Where the mean factors are compared, X is simply substituted for the "0" potash. In Table 2 and Figure 1, A, the efficiency factors of 020–120–220–420, all of which are significant, appear in a constantly increasing order. In the single phosphorus series (010–110–210–410) nitrogen apparently has a depressing effect, although only one of the nitrogen treatments is statistically significant. A comparison of the efficiency factors in the series 040–140–240–440 shows an upward tendency in phosphorus efficiency reaching the maximum in treatment 240.

The mean efficiency factors in Figure 1, B, may be similarly compared. All these factors are statistically significant, according to Table 2. With low phosphorus constant in series 01X–11X–21X–41X, nitrogen in larger quantities than the single dosage exercises a depressing effect. This tendency also appears in the nitrogen-phosphorus combinations (010–110–210–410), but the curves do not resemble each other very closely. The series 02X–12X–22X–42X and 04X–14X–24X–44X resemble each other in the increased efficiency shown by the single dosage of nitrogen, followed by a decline when heavier treatments are applied. There is no resemblance between these two curves in Figure 1, B, and those in Figure 1, A, for the series containing equivalent amounts of nitrogen and phosphorus.

TABLE 2.—*Comparison of the effect of nitrogen on the mean percentage increases in yields of edible green sweet corn and of green sweet-corn fodder, and on the efficiency of phosphorus, basis of percentages*

GREEN SWEET CORN

Treatment	Increase in yield	P efficiency factor	Treatment	Increase in yield	P efficiency factor	Treatment	Increase in yield	P efficiency factor
010	22.63±4.8	22.63±4.8	020	10.02±2.7	10.02±2.7	040	19.45±4.0	19.45±4.0
011	13.91±4.0	22.89±4.8	021	18.75±4.3	27.73±5.1	041	37.41±4.8	46.39±5.5
012	17.99±5.0	16.36±5.2	022	18.52±4.6	16.89±4.9	042	37.28±4.5	35.65±4.8
014	27.62±5.4	24.04±6.3	024	21.36±3.4	17.78±4.7	044	43.50±6.5	39.92±7.2
Mean	20.54±2.4	21.48±2.7	Mean	17.16±1.9	18.10±2.0	Mean	34.41±2.5	35.35±2.8
110	12.62±2.7	7.11±5.7	120	28.93±3.9	23.42±6.3	140	30.12±6.1	24.61±7.9
111	9.07±3.5	21.48±7.4	121	34.47±4.7	46.88±6.8	141	32.76±6.3	45.17±9.0
112	34.73±5.3	32.84±7.1	122	44.47±8.1	42.58±9.4	142	40.11±5.8	38.22±7.5
114	38.54±5.1	43.24±6.4	124	31.11±5.3	35.81±6.6	144	55.58±7.7	60.28±8.6
Mean	23.74±2.1	26.17±3.3	Mean	34.74±2.4	37.17±3.7	Mean	39.64±3.3	42.07±4.1
210	4.96±5.5	7.87±5.9	220	31.50±4.1	34.41±5.3	240	29.16±4.1	32.07±4.6
211	14.45±5.0	21.62±5.3	221	31.92±5.2	39.09±5.5	241	26.20±4.8	33.37±5.1
212	31.95±6.3	34.86±7.9	222	29.93±5.2	32.84±7.1	242	25.66±7.3	28.57±8.7
214	25.10±5.2	19.78±7.9	224	16.50±5.9	11.18±8.3	244	27.27±3.1	21.95±6.7
Mean	19.12±2.8	21.03±3.4	Mean	27.46±2.6	29.38±3.3	Mean	27.07±2.5	28.99±3.2
410	14.81±4.9	19.66±5.5	420	38.98±4.4	43.83±5.1	440	15.73±4.0	20.58±4.8
411	16.06±5.1	−1.32±6.1	421	22.35±7.0	4.97±7.7	441	24.94±2.7	7.56±4.3
412	12.14±3.3	15.15±5.4	422	32.04±3.2	35.05±5.4	442	13.13±3.1	16.14±5.3
414	30.12±7.0	32.36±7.9	424	35.53±2.5	37.77±4.5	444	5.89±3.1	8.13±4.8
Mean	18.28±2.6	16.46±3.1	Mean	32.22±2.3	30.40±2.9	Mean	14.92±1.6	13.10±2.4

GREEN SWEET-CORN FODDER

010	15.64± 4.0	15.64± 4.0	410	−1.55± 7.8	0.03± 8.2	220	7.74± 4.6	12.60± 5.5
011	10.97± 3.8	23.21± 8.1	411	18.05± 4.2	1.42± 6.1	221	27.78± 4.8	33.03± 5.6
012	13.58± 4.4	8.51± 5.6	412	19.45± 5.1	13.19± 6.8	222	38.69± 4.7	38.89± 8.1
014	39.36± 5.0	41.80± 6.1	414	29.89± 6.0	32.26± 7.6	224	42.88± 5.4	18.22± 8.1
Mean	19.89± 2.2	22.29± 3.1	Mean	16.46± 3.0	11.72± 3.6	Mean	29.27± 2.4	25.68± 3.5
110	14.71± 3.6	4.97± 8.9	020	11.46± 4.1	11.46± 4.1	420	31.56± 6.1	33.14± 6.6
111	−1.77± 3.0	−3.86± 7.6	021	23.18± 4.0	35.42± 8.2	421	13.65± 6.2	−2.98± 7.6
112	42.34± 5.3	14.12± 6.7	022	25.62± 5.3	20.55± 6.3	422	35.15± 4.5	28.89± 6.4
114	35.91± 3.8	28.21± 6.7	024	33.74± 5.0	36.18± 6.1	424	40.80± 4.6	43.17± 6.6
Mean	22.80± 2.0	10.86± 3.8	Mean	23.50± 2.3	25.90± 3.2	Mean	30.29± 2.7	25.56± 3.4
210	1.01± 5.0	5.87± 5.8	120	13.91± 3.3	4.17± 8.7	040	1.26±31.5	1.26±31.5
211	10.04± 3.1	15.29± 4.2	121	26.66± 5.7	24.57± 9.0	041	32.29± 5.2	44.53± 8.9
212	19.79± 6.4	19.99± 9.2	122	34.30± 6.5	6.08± 7.7	042	33.02± 5.7	27.95± 6.6
214	29.81± 4.4	5.15± 7.4	124	36.24± 6.4	28.54± 8.4	044	47.62± 5.2	50.06± 6.3
Mean	15.16± 2.4	11.58± 3.4	Mean	27.78± 2.8	15.84± 4.2	Mean	28.55± 8.2	30.95± 8.5

TABLE 2.—*Comparison of the effect of nitrogen on the mean percentage increases in yields of edible green sweet corn and of green sweet-corn fodder, and on the efficiency of phosphorus, basis of percentages*—Continued

GREEN SWEET-CORN FODDER—Continued

Treatment	Increase in yield	P efficiency factor	Treatment	Increase in yield	P efficiency factor	Treatment	Increase in yield	P efficiency factor
140	23.09± 4.9	13.35± 9.5	240	38.06± 5.4	42.92± 6.2	440	26.32± 4.9	27.90± 5.5
141	35.46± 5.7	33.37± 9.0	241	33.20± 6.0	38.45± 6.6	441	34.85± 5.9	18.22± 7.4
142	48.45± 4.4	20.23± 6.0	242	40.71± 6.7	40.91± 9.4	442	21.74± 2.6	15.48± 5.2
144	68.36± 8.6	60.66±10.2	244	52.05± 5.2	27.39± 7.9	444	19.01± 3.5	21.38± 5.9
Mean	43.84± 3.1	31.90± 4.4	Mean	41.00± 2.9	37.42± 3.8	Mean	25.48± 2.2	20.74± 3.0

The effect of nitrogen as determined by green fodder is shown in Table 2 and Figure 1, C and D. The depressive effect of nitrogen upon phosphorus in the series 010–110–210–410 is rather marked. The tendency shown here is similar to that found in edible ears. In the two series 020–120–220–420 and 040–140–240–440, nitrogen has a variable but, in some dosages, stimulating effect.

The mean factors in Figure 1, D, are all statistically significant with the exception of treatment 11X. (Table 2.) Again there appears the depressive effect of nitrogen upon the single dosage of phosphorus (01X–11X–21X–41X). Nitrogen in the series 02X–12X–22X–42X and 04X–14X–24X–44X has but little stimulating effect and a considerably depressive one in certain treatments (12X and 44X).

No consideration has been given thus far to the efficiency of phosphorus when this element is applied in increasing amounts with nitrogen held constant. Such comparisons are made in Figure 2 and may be summarized as follows:

010–020–040.
110–120–140.
210–220–240.
410–420–440.

The letter X is simply substituted in place of the 0 potash when the mean factors are compared.

On the basis of edible ears (fig. 2, A) the double phosphorus dosage is consistently more efficient than any other in combination of nitrogen and phosphorus. At the same time it is statistically significant in all cases in Figure 2, A. Phosphorus applied alone gives rather unexpected results inasmuch as the single dosage is the most efficient.

A comparison of the mean factors in Figure 2, B, shows that where nitrogen is used the double phosphorus dosage is the most efficient in two cases out of three, and in the third, 12X is only slightly inferior to 14X. Omitting nitrogen (01X–02X–04X) gives an irregular trend, 04X being more efficient than any other combination in the series.

Comparisons of the effect of the dosage of phosphorus on the efficiency factors for fodder are shown in Figure 2, C and D, which have been derived from Table 2. As in the case of edible ears, phosphorus applied alone has a tendency to decrease in efficiency as the size of the application increases. When phosphorus is combined with nitrogen, however, there is a general tendency for its efficiency to increase in relation to the dosage, with the single exception of treatment 120.

The mean efficiency factors show a similar trend (fig. 2, D) when nitrogen is present, that is, the efficiency tends to increase in relation to the amount applied. Omitting nitrogen, as in series 01X–02X–04X, fails to change this trend.

From the preceding discussion it is apparent that under certain conditions in these experiments, nitrogen may have a considerable influence upon the efficiency of phosphorus. With a dosage of 32 pounds P_2O_5 per acre constant, nitrogen seems to act in general as a depressive agent. On the other hand, with 64 or 128 pounds P_2O_5 per acre constant, there is a general tendency for nitrogen in treatments of 7.5 and 15 pounds per acre to increase the efficiency of phosphorus. Edible ears are somewhat more consistent in their response than is fodder, according to Figure 1, C and D.

The efficiency of phosphorus changes considerably according to the amount applied. In combinations containing nitrogen but no potash there is a marked tendency for phosphorus to increase in efficiency in relation to the amount applied. This is in striking contrast with the effect shown by phosphorus applied alone, where the increased dosage gives a decreased efficiency. A comparison of edible ears with fodder shows that the double application of phosphorus is as efficient as the quadruple application on the edible-ear basis, or more so, but on the fodder basis the reverse is true.

The trends shown by the mean efficiency factors differ in some instances from those of the nitrogen-phosphorus combinations. In the former, the single dosage of nitrogen, using edible ears as a basis, is the most efficient, whereas in the latter heavier nitrogen applications seem to be superior. A comparison of the trends shown by the two series 010–020–040 and 01X–02X–04X indicates that potash is also an important factor in influencing the efficiency of phosphorus. This will be discussed later.

EFFECT OF PHOSPHORUS ON THE EFFICIENCY OF NITROGEN

The data showing the effect of phosphorus on the efficiency of nitrogen appear in Table 3 and in Figures 3 and 4.

Considering first the results obtained from edible ears (Table 3 and fig. 3, A and B) it is evident that the single dosage of phosphorus has a slight to depressing effect on nitrogen efficiency. The results, however, are not statistically significant. The double phosphorus dosage has a uniformly distinct and significant stimulating effect on nitrogen.

A study of the results from fodder (Table 3 and fig. 3, C and D) shows that the single phosphorus dosage is depressive, whereas in general the double and quadruple dosages are stimulating. Since almost all the factors lack statistical significance, this can only be considered as a trend.

The curves in Figure 4, A and B, show the effect of increasing dosages of nitrogen upon its own efficiency (edible-ear basis), phosphorus being held constant. The only factors in Figure 4, A, having statistical significance are in the series 120–220–420; in this series nitrogen increases somewhat in efficiency. The remaining curves of Figure 4, A, show that increasing the dosages of nitrogen tends to reduce its efficiency.

In Figure 4, B, the series 12X–22X–42X, in which the factors are statistically significant, shows a somewhat variable but slightly downward trend. The remaining curves, with the exception of 10X–20X–40X, show that nitrogen has a tendency to decrease in efficiency as the dosage increases.

The curves for fodder (fig. 4, C and D) are derived from Table 3. In Figure 4, C, there is a good deal of variation. Thus in the series 100–200–400 and 110–210–410 increasing the nitrogen tends to decrease its efficiency. With larger amounts of phosphorus constant, nitrogen shows a partially reverse tendency. The mean factors in Figure 4, D, are much more consistent, and nitrogen in increasing amounts seems either to have no appreciable effect upon its

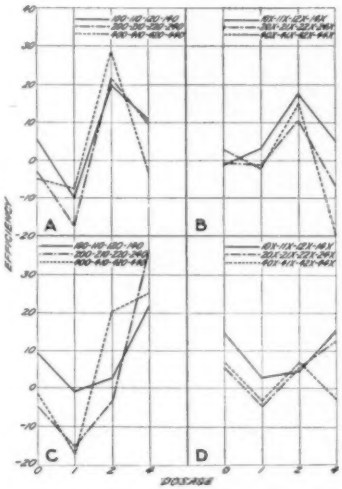

FIGURE 3.—The effect of successive increments of phosphorus on the efficiency of nitrogen, both with and without potash; results for two elements shown in A and C, for three elements in B and D, for edible ears in A and B, and for green fodder in C and D

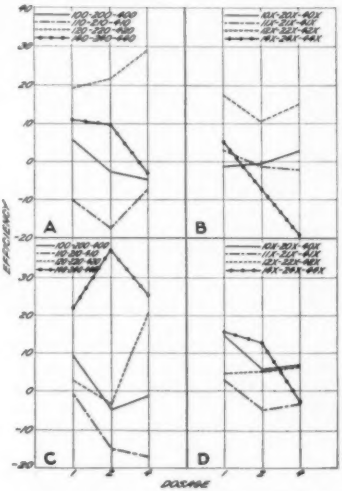

FIGURE 4.—The effect of successive increments of nitrogen on its efficiency in nitrogen-phosphorus combinations, both with and without potash; results for two elements shown in A and C, for three elements in B and D, for edible ears in A and B, and for green fodder in C and D

efficiency, or a depressive one. These results are to be regarded only as tendencies, however, since but one of the efficiency factors is statistically significant.

The discussion of the effect of phosphorus on nitrogen efficiency emphasizes the importance of the double dosage of phosphorus in the production of edible ears, inasmuch as it increases the efficiency of nitrogen to a significant degree. On the other hand, applications of 32 pounds P_2O_5 per acre have a depressive effect as compared with no phosphorus. The results from fodder agree with the foregoing to the extent of confirming the depressive tendency of the single phosphorus dosage, but the quadruple phosphorus dosage is in general more efficient than the double one.

The curves which interpret the effect of the dosage of nitrogen upon its efficiency show that in most instances, except those noted above, the single dosage is as efficient as the heavier applications, or more so. Thus, the analysis brings out two points of importance, namely, that the single dosage of nitrogen and the double dosage of phosphorus appear to be the most efficient, the latter from the standpoint of producing edible ears.

TABLE 3.—*Comparison of the effect of phosphorus on the mean percentage increases in yields of edible green sweet corn and of sweet-corn fodder, and on the efficiency of nitrogen, basis of percentages*

EDIBLE GREEN SWEET CORN

Treatment	Increase in yield	N efficiency factor	Treatment	Increase in yield	N efficiency factor	Treatment	Increase in yield	N efficiency factor
100	5.51±5.0	5.51± 5.0	200	−2.91±2.2	−2.91± 2.2	400	−4.85±2.6	−4.85± 8.1
101	−12.41±6.5	−3.43± 7.0	201	−7.17±1.8	1.81± 3.2	401	17.38±3.3	26.36± 4.3
102	1.89±4.7	.26± 4.9	202	−2.91±4.8	−4.54± 5.0	402	−3.01±4.3	−4.64± 4.6
104	−4.70±3.9	−8.28± 5.0	204	5.32±5.9	1.74± 6.7	404	−2.24±3.7	−5.82± 4.9
Mean	−2.43±2.6	−1.48± 2.8	Mean	−1.92±2.0	−.98± 2.3	Mean	1.82±1.8	2.76± 2.8
110	12.62±2.7	−10.01± 5.5	210	4.96±5.5	−17.67± 7.3	410	14.81±4.9	−7.82± 6.8
111	9.07±3.5	−4.84± 5.3	211	14.45±5.0	.54± 6.4	411	16.06±5.1	2.15± 6.5
112	34.73±5.3	16.74± 7.3	212	31.95±6.3	13.96± 8.0	412	12.14±3.3	−5.85± 6.0
114	38.54±5.1	10.92± 7.4	214	25.10±5.2	−2.52± 7.5	414	30.12±7.0	2.50± 8.8
Mean	23.74±2.1	3.20± 3.2	Mean	19.12±2.8	−1.42± 3.7	Mean	18.28±2.6	−2.26± 3.6
120	28.93±3.9	18.91± 4.7	220	31.50±4.8	21.48± 5.5	420	38.98±4.4	28.96± 5.2
121	34.47±4.7	15.72± 6.4	221	31.92±5.2	13.17± 6.5	421	22.35±7.0	3.60± 8.2
122	44.47±8.1	25.95± 9.3	222	29.93±5.2	11.41± 6.9	422	32.04±3.2	13.52± 5.6
124	31.11±5.3	9.75± 6.3	224	16.50±5.9	−4.86± 6.8	424	35.53±2.5	14.17± 4.2
Mean	34.74±2.9	17.58± 3.4	Mean	27.46±2.6	10.30± 3.2	Mean	32.22±2.3	15.06± 3.0
140	30.12±6.1	10.67± 7.3	240	29.16±4.1	9.71± 5.7	440	15.73±4.0	−3.72± 5.6
141	32.76±6.3	−4.65± 7.9	241	26.20±4.8	−11.21± 6.8	441	24.94±2.7	−12.47± 5.5
142	40.11±5.8	2.83± 7.3	242	25.66±7.3	−11.62± 8.6	442	13.13±3.1	−24.15± 5.5
144	55.58±7.7	12.08±10.1	244	27.27±3.1	−16.23± 7.2	444	5.89±3.1	−37.61± 7.2
Mean	39.64±3.3	5.23± 4.1	Mean	27.07±2.5	−7.34± 3.6	Mean	14.92±1.6	−19.49± 3.0

SWEET CORN FODDER

100	9.74±8.1	9.74± 8.1	200	−4.86±3.0	−4.86± 3.0	400	−1.58±2.6	−1.58± 2.6
101	2.09±7.0	14.33±10.0	201	−5.25±2.8	6.99± 2.9	401	16.63±4.4	28.87± 4.4
102	28.22±4.1	23.15± 5.3	202	−.20±6.6	−5.27± 7.4	402	6.26±4.5	1.19± 5.6
104	7.70±5.5	10.14± 6.5	204	24.66±6.0	27.10± 6.9	404	−2.37±4.7	.07± 5.9
Mean	11.94±3.2	14.34± 3.8	Mean	3.59±2.4	5.99± 2.7	Mean	4.74±2.1	7.14± 2.4
110	14.71±3.6	−.93± 5.4	210	1.01±5.0	−14.63± 6.4	410	−1.55±7.8	−17.19± 8.8
111	−1.77±3.0	−12.74± 4.8	211	10.04±3.1	−.93± 4.9	411	18.05±4.2	7.08± 5.7
112	42.34±5.3	28.76± 6.9	212	19.79±6.4	6.21± 7.8	412	19.45±5.1	5.87± 6.7
114	35.91±3.8	−3.45± 6.3	214	29.81±4.4	−9.55± 6.7	414	29.89±6.0	−9.47± 7.8
Mean	22.80±2.0	2.91± 3.0	Mean	15.16±2.4	−4.72± 3.3	Mean	16.46±3.0	−3.43± 3.7
120	13.91±3.3	2.45± 5.3	220	7.74±4.6	−3.72± 6.2	420	31.56±6.1	20.10± 7.4
121	26.66±5.7	3.48± 7.0	221	27.78±4.8	4.60± 6.3	421	13.65±6.2	−9.53± 7.4
122	34.30±6.5	8.68± 8.4	222	38.69±4.7	13.07± 7.1	422	35.15±4.5	9.53± 7.0
124	36.24±6.4	2.50± 8.1	224	42.88±5.4	9.14± 7.4	424	40.80±4.6	7.06± 6.8
Mean	27.78±2.8	4.28± 3.6	Mean	29.27±2.4	5.77± 3.4	Mean	30.29±2.7	6.79± 3.6
140	23.09±4.9	21.83±31.9	240	38.06±5.4	36.80±32.0	440	26.32±4.9	25.06±31.9
141	35.46±5.7	3.17± 7.7	241	33.20±6.0	.91± 7.9	441	34.85±5.9	2.56± 7.9
142	48.45±4.4	15.43± 7.2	242	40.71±6.7	7.69± 8.8	442	21.74±2.6	−11.28± 6.3
144	68.36±8.6	20.74±10.0	244	52.05±5.2	4.43± 7.4	444	19.01±3.5	−28.61± 6.3
Mean	43.84±3.1	15.29± 8.8	Mean	41.00±2.9	12.46± 8.7	Mean	25.48±2.2	−3.07± 8.5

EFFECT OF NITROGEN ON THE EFFICIENCY OF POTASH

The effect of nitrogen on the efficiency of potash is shown in Table 4 and Figures 5 and 6.

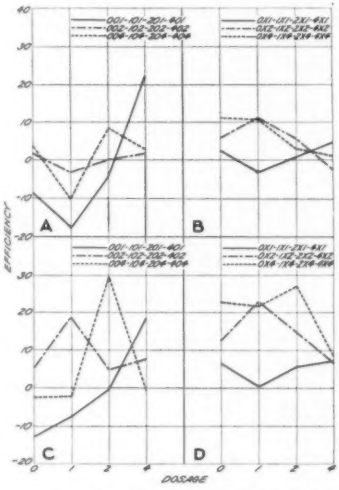

FIGURE 5.—The effect of successive increments of nitrogen on the efficiency of potash, both with and without phosphorus; results for two elements shown in A and C, for three elements in B and D, for edible ears in A and B, and for green fodder in C and D

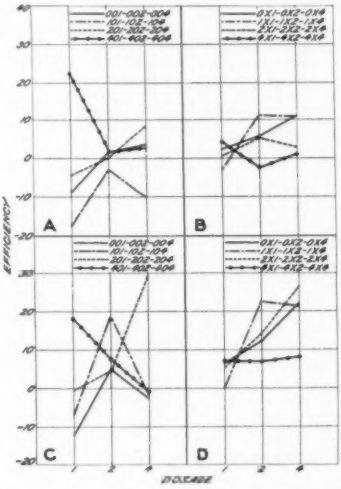

FIGURE 6.—The effect of successive increments of potash on its efficiency in nitrogen-potash combinations, both with and without phosphorus; results for two elements shown in A and C, for three elements in B and D, for edible ears in A and B, and for green fodder in C and D

TABLE 4.—*Comparison of the effect of nitrogen on the mean percentage increases in yields of edible green sweet corn and of sweet-corn fodder, and on the efficiency of potash, basis of percentages*

EDIBLE GREEN SWEET CORN

Treatment	Increase in yield	K efficiency factor	Treatment	Increase in yield	K efficiency factor	Treatment	Increase in yield	K efficiency factor
001	−8.98±2.7	−8.98±2.7	002	1.63±1.6	1.63±1.6	004	3.58±3.2	3.58±3.2
011	13.91±4.0	−8.72±6.2	012	17.99±5.0	−4.64±6.9	014	27.62±5.4	4.99±7.2
021	18.75±4.3	8.73±5.1	022	18.52±4.6	8.50±5.3	024	21.36±3.4	11.34±4.3
041	37.41±4.8	17.96±6.2	042	37.28±4.5	17.83±6.0	044	43.50±6.5	24.05±7.6
Mean	15.27±2.0	2.25±2.6	Mean	18.86±2.1	5.83±2.7	Mean	24.02±2.4	10.99±2.9
101	−12.41±6.5	−17.92±8.2	102	1.89±4.7	−3.62±6.9	104	−4.70±3.9	−10.21±6.3
111	9.07±3.5	−3.55±4.4	112	34.73±5.3	22.11±5.9	114	38.54±5.1	25.92±5.8
121	34.47±4.7	5.54±6.1	122	44.47±8.1	15.54±9.0	124	31.11±5.3	2.18±6.6
141	32.76±6.3	2.64±8.8	142	40.11±5.8	9.99±8.4	144	55.58±7.7	25.46±9.8
Mean	15.97±2.7	−3.32±3.5	Mean	30.30±3.0	11.00±3.8	Mean	30.13±2.8	10.84±3.6
201	−7.17±1.8	−4.26±2.8	202	−2.91±4.8	0	204	5.32±5.9	8.23±6.3
211	14.45±5.0	9.49±7.4	212	31.95±6.3	26.99±8.4	214	25.10±5.2	20.14±7.6
221	31.92±5.2	.42±7.1	222	29.93±5.2	−1.57±7.1	224	16.50±5.9	−15.00±7.6
241	26.20±4.8	−2.96±6.3	242	25.66±7.3	−3.50±8.4	244	27.27±3.1	−1.89±5.1
Mean	16.35±2.2	.67±3.1	Mean	21.16±3.0	5.48±3.5	Mean	18.55±2.6	2.87±3.4
401	17.38±3.3	22.23±4.2	402	−3.01±4.3	1.84±5.0	404	−2.24±3.7	2.61±4.5
411	16.06±5.1	1.25±7.1	412	12.14±3.3	−2.67±5.9	414	30.12±7.0	15.31±8.5
421	22.35±7.0	−16.63±8.3	422	32.04±3.2	−6.94±5.4	424	35.53±2.5	−3.45±5.1
441	24.94±2.7	9.21±4.8	442	13.13±3.1	−2.60±5.1	444	5.89±3.1	−9.84±5.1
Mean	20.18±2.4	4.04±3.2	Mean	13.58±1.8	−2.59±2.7	Mean	17.32±2.2	1.16±3.0

TABLE 4.—*Comparison of the effect of nitrogen on the mean percentage increases in yields of edible green sweet corn and of sweet-corn fodder, and on the efficiency of potash, basis of percentages*—Continued

GREEN SWEET-CORN FODDER

Treatment	Increase in yield	K efficiency factor	Treatment	Increase in yield	K efficiency factor	Treatment	Increase in yield	K efficiency factor
001	−12.24±7.2	−12.24± 7.2	002	5.07±3.4	5.07± 3.4	004	−2.44±3.5	−2.44± 3.5
011	10.97±3.8	−4.67± 5.5	012	13.58±4.4	−2.06± 5.9	014	39.36±5.0	23.72± 6.4
021	23.18±4.0	11.72± 5.7	022	25.62±5.3	14.16± 6.8	024	33.74±5.0	22.28± 6.5
041	32.29±5.2	31.03±31.9	042	33.02±5.7	31.76±32.0	044	47.62±5.2	46.36±31.9
Mean	13.55±2.6	6.46± 8.4	Mean	19.32±2.4	12.23± 8.4	Mean	29.57±2.4	22.48± 8.3
101	2.09±7.0	−7.65±10.7	102	28.22±4.1	18.48±9.1	104	7.70±5.5	−2.04±9.8
111	−1.77±3.0	−16.48± 4.7	112	42.34±5.3	27.63±6.3	114	35.91±3.8	21.20±5.2
121	26.66±5.7	12.75± 6.6	122	34.30±6.5	20.39±7.3	124	36.24±6.4	22.33±7.2
141	35.46±5.7	12.37± 7.5	142	48.45±4.4	25.36±6.6	144	68.36±8.6	45.27±9.9
Mean	15.61±2.8	.25± 3.8	Mean	38.33±2.6	22.96±3.7	Mean	37.05±3.2	21.69±4.1
201	−5.25±2.8	−.39±4.1	202	−.20±6.6	4.66±7.2	204	24.66±6.0	29.52±6.7
211	10.04±3.1	9.03±5.9	212	19.79±6.4	18.78±8.1	214	29.81±4.4	28.80±6.7
221	27.78±4.8	20.04±6.6	222	38.69±4.7	30.95±6.6	224	42.88±5.4	35.14±7.1
241	33.20±6.0	−4.86±8.1	242	40.71±6.7	2.65±8.6	244	52.05±5.2	13.99±7.5
Mean	16.44±2.2	5.96±3.2	Mean	24.75±3.1	14.26±3.8	Mean	37.35±2.6	26.86±3.5
401	16.63±4.4	18.21±5.1	402	6.26±4.5	7.84±5.2	404	−2.37±4.7	−.79±5.4
411	18.05±4.2	19.60±8.9	412	19.45±5.1	21.00±9.3	414	29.89±6.0	31.44±9.8
421	13.65±6.2	−17.91±8.7	422	35.15±4.5	3.59±7.6	424	40.80±4.6	9.24±7.6
441	34.85±5.9	8.53±7.7	442	21.74±2.6	−4.58±5.5	444	19.01±3.5	−7.31±6.0
Mean	20.80±2.6	7.11±3.9	Mean	20.65±2.1	6.96±3.5	Mean	21.83±2.4	8.14±3.7

The striking feature about the curves in Figures 5 and 6 is the persistent recurrence of three ratios of nitrogen and potash, 2:4, 1:2, and 4:1. Expressing the ratios in terms of N and K_2O per acre they would be 15–0–100, 7.5–0–50, and 30–0–25. The first two ratios, 15–0–100 and 7.5–0–50, merely differ as to quantity.

In nitrogen-potash mixtures where phosphorus is omitted, the efficiency of potash increases in relation to successive increments of nitrogen in but a single series, namely, 001–101–201–401, as shown in Figure 5, A, for edible ears and in Figure 5, C, for fodder. In this series, potash is constant with a single dosage. The mean factors which include phosphorus, when compared in the equivalent series, 0X1–1X1–2X1–4X1, show that 4X1 is the mode (fig. 5, B and D) for both ears and fodder, but the efficiency factors are both very small and not statistically significant. In the remaining curves of Figure 5, A and C, treatments 102 or 204 are the modes where there are any. Adding phosphorus as in Figure 5, B and D, does not change the modes except in one series, 0X4–1X4–2X4–4X4, where 0X4 is the highest treatment.

Most of the efficiency factors considered in Figure 5 lack statistical significance. However, the curves are consistent in their trends to an appreciable degree.

Considering next the effect of increasing amounts of potash upon its own efficiency, nitrogen being held constant, the curves in Figure 6, A and C, where phosphorus is omitted, show that the efficiency of potash increases when the double dosage of nitrogen is held constant and decreases when the quadruple nitrogen dosage is held constant. Treatments 102, 204, or 401 are the modes of the six curves, although but three of these, according to Table 4 are significant.

Where phosphorus is included (fig. 6, B and D) potash efficiency increases just about as rapidly in relation to added increments without nitrogen as with this element included. As a matter of act, in the case of edible ears the series 1X1–1X2–1X4 is the only one with nitrogen present that actually shows an increase higher than that where nitrogen is omitted. Fodder, on the other hand, gives increases in two series containing nitrogen, namely, 1X1–1X2–1X4 and 2X1–2X2–2X4.

Since the efficiency of potash is influenced to a considerable extent by nitrogen, it appears possible to draw certain general conclusions, with the reservation in mind, of course, that a considerable portion of the data have large probable errors. Figures 5 and 6 show the following:

With the single dosage of potash constant, the efficiency of potash tends to increase in relation to successive increments of nitrogen in mixtures containing no phosphorus (001–101–201–401).

With the double dosage of potash constant there is a considerable tendency for treatment 102 to be dominant where no phosphorus is used and 1X2 where phosphorus is included.

With the quadruple dosage of potash constant there is a tendency in the case of fodder for treatment 204 to give the maximum efficiency in mixtures omitting phosphorus and 2X4 where it is included.

Where successive increments of potash are added alone, there is a very slight tendency for the efficiency to increase in relation to the dosage, but this is confined to edible ears alone and the factors are not statistically significant.

In nitrogen-potash mixtures, treatments 102, 204, and 401 are dominant in general where the single, double, and quadruple dosages of nitrogen are held constant and potash increases. The probable errors in some instances are very large, however.

Increasing potash in phosphorus-potash mixtures likewise increases the efficiency of potash.

Increasing potash where phosphorus is included and nitrogen held constant shows that treatments 1X2, 2X4, and 4X1 are, with certain qualifications, dominant.

EFFECT OF POTASH ON THE EFFICIENCY OF NITROGEN

The discussion of the action of potash upon the efficiency of nitrogen is based on the data in Table 5 and Figures 7 and 8. The curves in Figure 7, A and C, and Figure 8, A and C, show that in N–K mixtures omitting P, treatments 102, 204, and 401 are dominant. All three are statistically significant on the fodder basis, only 401 on the ear basis. In Figure 7, B and D, and Figure 8, B and D, the modes for the mean factors show that 1X2, 2X4, and 4X1 are dominant on the fodder basis, but 1X2 is the only significant treatment. On the ear basis the factors are small and the probable errors large, so that no use can be made of the data.

If the N–K mixtures are arranged so that N increases and K remains constant as in Figure 8, A and C, then 102, 204 and 401 are again dominant. With respect to the mean factors, 4X1, 1X2, and 1X4 are the dominant treatments on the fodder basis, according to Figure 8, D.

In determining the effect of nitrogen upon the efficiency of potash, and reciprocally the effect of potash upon the efficiency of nitrogen,

the constant recurrence of similar N–K ratios as modes in the curves is rather marked. The maximum efficiency of both nitrogen and potash seems to be attained in certain fairly well defined ratios; and while there is some variation in these tendencies, it will be observed that at the same time there are scarcely ever any substitutions for the 1:2, 2:4, and 4:1 ratios of N and K. In view of this behavior the following conclusions may be drawn: (1) Where small dosages of nitrogen such as 7.5 pounds per acre are used, the highest efficiency is attained in combination with a large dosage of potash such as 50 pounds K_2O per acre; (2) a doubled dosage of nitrogen (15 pounds per acre) apparently requires for the maximum efficiency double the amount of potash, that is, 100 pounds K_2O per acre; and (3) quadrupled dosages of nitrogen (30 pounds per acre), are almost always

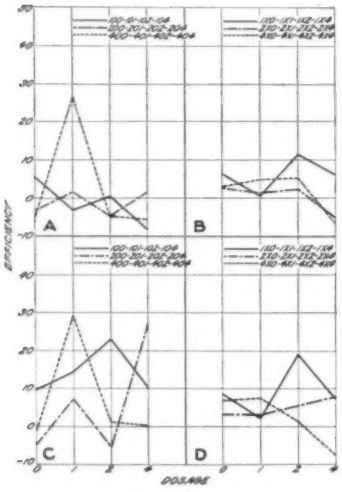

FIGURE 7.—The effect of successive increments of potash on the efficiency of nitrogen, both with and without phosphorus; results for two elements shown in A and C, for three elements in B and D, for edible ears in A and B, and for green fodder in C and D

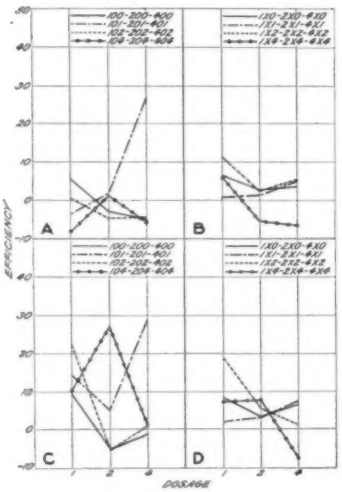

FIGURE 8.—The effect of successive increments of nitrogen on its efficiency in nitrogen-potash combinations, both with and without phosphorus; results for two elements shown in A and C, for three elements in B and D, for edible ears in A and B, and for green fodder in C and D

associated with the smallest potash dosage, that is, 25 pounds K_2O per acre.

The rather unusual feature is that potash affects nitrogen efficiency in practically the same manner as nitrogen affects potash efficiency. On this evidence alone, without supporting chemical data, one would assume that nitrogen can be used to replace potash, or that potash can be used to replace nitrogen.

This raises one of the most complex questions encountered in soils investigations—the question of the relations existing between nitrogen and potash and the determination of the optimum ratios between them. The trends shown by the curves in Figures 5, 6, 7, and 8 raise several interesting points essential to the successful solution of the problem. Briefly, the data in Figures 5 to 8 may be stated as

follows: (1) The 30–0–25 or 401 ratio is considerably higher in efficiency than are the 7.5–0–50 and the 15–0–100 (102 and 204) ratios on the basis of edible ears and tends to be equally efficient on the basis of green fodder; and (2) when phosphorus is included, the mean factors show that the 7.5–X–50 (1X2) ratio is usually considerably better than either the 15–X–100 (2X4) or the 30–X–25 (4X1) ratio as based on both edible ears and fodder.

TABLE 5.—*Comparison of the effect of potash on the mean percentage increases in yields of edible green sweet corn and of sweet-corn fodder, and on the efficiency of nitrogen, basis of percentages*

EDIBLE GREEN SWEET CORN

Treatment	Increase in yield	N efficiency factor	Treatment	Increase in yield	N efficiency factor	Treatment	Increase in yield	N efficiency factor
100	5.51±5.0	5.51±5.0	200	−2.91±2.2	−2.91± 2.2	400	−4.85±2.6	−4.85± 2.6
110	12.62±2.7	−10.01±5.5	210	4.96±5.5	−17.67± 7.3	410	14.81±4.9	−7.82± 6.8
120	28.93±3.9	18.91±4.7	220	31.50±4.8	21.48± 5.5	420	38.98±4.4	28.96± 5.2
140	30.12±6.1	10.67±7.3	240	29.16±4.1	9.71± 5.7	440	15.73±4.0	−3.72± 5.6
Mean	19.30±2.3	6.27± 2.8	Mean	15.68±2.2	2.65±2.7	Mean	16.17±2.0	3.14± 2.6
101	−12.41±6.5	−3.43± 7.0	201	−7.17±1.8	1.81± 3.2	401	17.38±3.3	26.36± 4.3
111	9.07±3.5	−4.84± 5.3	211	14.45±5.0	.54± 6.4	411	16.06±5.1	2.15± 6.5
121	34.47±4.7	15.72± 6.4	221	31.92±5.2	13.17± 6.7	421	22.35±7.0	3.60± 8.2
141	32.76±6.3	−4.65± 7.9	241	26.20±4.8	−11.21± 6.8	441	24.94±2.7	−12.47± 5.5
Mean	15.97±2.7	.70± 3.4	Mean	16.35±2.2	1.08± 3.0	Mean	20.18±2.4	4.91± 3.2
102	1.89±4.7	.26± 4.9	202	−2.91±4.8	−4.54± 5.0	402	−3.01±4.3	−4.64± 4.6
112	34.73±5.3	16.74± 7.3	212	31.95±6.3	13.96± 8.0	412	12.14±3.3	−5.85± 6.0
122	44.47±8.1	25.95± 9.8	222	29.93±5.2	11.41± 6.9	422	32.04±3.2	13.52± 5.6
142	40.11±5.8	2.83± 7.3	242	25.66±7.3	−11.62± 8.6	442	13.13±3.1	−24.15±5.5
Mean	30.30±3.1	11.44± 3.7	Mean	21.16±3.0	2.30± 3.6	Mean	13.58±1.8	5.28± 2.7
104	−4.70±3.9	−8.28± 5.0	204	5.32±5.9	1.74± 6.7	404	−2.24±3.7	−5.82± 4.9
114	38.54±5.1	10.92± 7.4	214	25.10±5.2	−2.52± 7.5	414	30.12±7.0	2.50± 8.8
124	31.11±5.3	9.75± 6.3	224	16.50±5.9	−4.86± 6.8	424	35.53±2.5	14.17± 4.2
144	55.58±7.7	12.08±10.1	244	27.27±3.1	−16.23±7.2	444	5.89±3.1	−37.61± 7.2
Mean	30.13±2.8	6.12±3.7	Mean	18.55±2.6	−5.47± 3.5	Mean	17.32±2.2	−6.69± 3.3

GREEN SWEET-CORN FODDER

Treatment	Increase in yield	N efficiency factor	Treatment	Increase in yield	N efficiency factor	Treatment	Increase in yield	N efficiency factor
100	9.74±8.1	9.74± 8.1	200	−4.86±3.0	−4.86± 3.0	400	−1.58±2.6	−1.58± 2.6
110	14.71±3.6	−.93± 5.4	210	1.01±5.0	−14.63± 6.4	410	−1.55±7.8	−17.19± 8.8
120	13.91±3.3	2.45± 5.3	220	7.74±4.6	−3.72± 6.2	420	31.56±6.1	20.10± 7.4
140	23.09±4.9	21.83±31.9	240	38.06±5.4	36.80±32.0	440	26.32±4.9	25.06±31.9
Mean	15.36±2.7	8.27± 8.4	Mean	10.49±2.3	3.40± 8.3	Mean	13.69±2.8	6.60± 8.5
101	2.09±7.0	14.33±10.0	201	−5.25±2.8	6.99± 2.9	401	16.63±4.4	28.87± 4.4
111	−1.77±3.0	−12.74± 4.8	211	10.04±3.1	−.93± 4.9	411	18.05±4.2	7.08± 5.7
121	26.66±5.7	3.48± 7.0	221	27.78±4.8	4.60± 6.3	421	13.65±6.2	−9.53± 7.4
141	35.46±5.7	3.17± 7.7	241	33.20±6.0	.91± 7.9	441	34.85±5.9	2.56± 7.9
Mean	15.61±2.8	2.06±3.8	Mean	16.44±2.2	2.89± 2.9	Mean	20.80±2.6	7.25± 3.2
102	28.22±4.1	23.15± 5.3	202	−.20±6.6	−5.27± 7.4	402	6.26±4.5	1.19± 5.6
112	42.34±5.3	28.76± 6.9	212	19.79±6.4	6.21± 7.8	412	19.45±5.1	5.87± 6.7
122	34.30±6.5	8.68± 8.4	222	38.69±4.7	13.07± 7.1	422	35.15±4.5	9.53± 7.0
142	43.45±4.4	15.43± 7.2	242	40.71±6.7	7.69± 8.8	442	21.74±2.6	−11.28± 6.3
Mean	38.33±2.6	19.00± 3.5	Mean	24.75±3.1	5.42± 3.9	Mean	20.65±2.1	1.33± 3.2
104	7.70±5.5	10.14± 6.5	204	24.66±6.0	27.10± 6.9	404	−2.37±4.7	.07± 5.9
114	35.91±3.8	−3.45± 6.3	214	29.81±4.4	−9.55± 6.7	414	29.89±6.0	−9.47± 7.8
124	36.24±6.4	2.50± 8.1	224	42.88±5.4	9.14± 7.4	424	40.80±4.6	7.06± 6.8
144	68.36±8.6	20.74±10.0	244	52.05±5.2	4.43± 7.4	444	19.01±3.5	−28.61± 6.3
Mean	37.05±3.2	7.48± 3.9	Mean	37.35±2.6	7.78± 3.6	Mean	21.83±2.4	−7.74± 3.4

From these results it appears that on soils of the type used here the fact that a ratio of nitrogen and potash such as the 30–0–25 gives the highest efficiency, might indicate that phosphorus is still to some extent a limiting factor. When the phosphorus requirement is satisfied, there should be a tendency toward greater efficiency in the direction of higher potassium and lower nitrogen.

THE EFFECT OF POTASH ON THE EFFICIENCY OF PHOSPHORUS

The effect of potash on the efficiency of phosphorus is given in Table 6, and Figures 9 and 10.

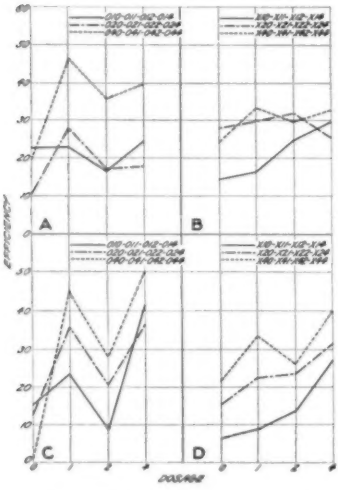

FIGURE 9.—The effect of successive increments of potash on the efficiency of phosphorus, both with and without nitrogen; results for two elements shown in A and C, for three element in B and D, for edible ears in A and B, and for green fodder in C and D

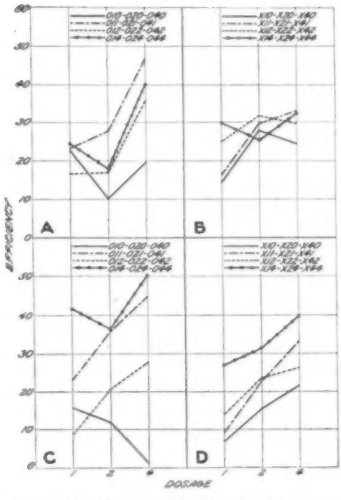

FIGURE 10.—The effect of successive increments of phosphorus on its efficiency in phosphorus-potash combinations, both with and without nitrogen, results for two elements shown in A and C, for three elements in B and D, for edible ears in A and B, and for green fodder in C and D

The curves in Figure 9, A, show that on the basis of edible ears, the efficiency of phosphorus does not tend to increase beyond the single dosage of potash. In one series, namely 010–011–012–014, potash seems to have but a very slight effect.

A somewhat different relationship is shown by the mean factors, where nitrogen is included, in Table 6 and Figure 9, B. The modes of the three curves are treatments X14, X22, and X41. In Figure 9, B, the curve for the series X40–X41–X42–X44 appears to be bimodal, treatment X44 being virtually the same as X41. The comparison of these four modes, namely, X14, X22, X41, and X44, indicates that although the treatments differ radically, the phosphorus efficiency factors are virtually the same.

In Figure 10, A and B, the effect of increasing dosages of phosphorus upon the efficiency of this element is shown on the basis of edible ears. Where nitrogen is omitted (fig. 10, A), phosphorus increases in efficiency in relation to the dosage, but not where it is used alone. Where nitrogen is included in Figure 10, B, the mean factors show

that treatments X20, X41, X22, X44, and X14 are the modes. In other words, the most efficient dosages are in one instance, low phosphorus; in two instances, double phosphorus; and in two, quadruple phosphorus, assuming curve X14–X24–X44 to be bimodal. From the data in Table 6 it appears that the differences between the efficiency factors for these treatments are very slight indeed.

TABLE 6.—*Comparison of the effect of potash on the mean percentage increases in yields of edible green sweet corn and of sweet-corn fodder, and on the efficiency of phosphorus, basis of percentages*

EDIBLE GREEN SWEET CORN

Treatment	Increase in yield	P efficiency factor	Treatment	Increase in yield	P efficiency factor	Treatment	Increase in yield	P efficiency factor
010	22.63±4.8	22.63±4.8	020	10.02±2.7	10.02±2.7	040	19.45±4.0	19.45±4.0
110	12.62±2.7	7.11±5.7	120	28.93±3.9	23.42±6.3	140	30.12±6.1	24.61±7.9
210	4.96±5.5	7.87±5.9	220	31.50±4.8	34.41±5.3	240	29.16±4.1	32.07±4.6
410	14.81±4.9	19.66±5.5	420	38.98±4.4	43.83±5.1	440	15.73±4.0	20.58±4.8
Mean	13.76±2.3	14.32±2.7	Mean	27.36±2.0	27.92±2.5	Mean	23.62±2.3	24.18±2.8
011	13.91±4.0	22.89±4.8	021	18.75±4.3	27.73±5.1	041	37.41±4.8	46.39±5.5
111	9.07±3.5	21.48±7.4	121	34.47±4.7	46.88±6.8	141	32.76±6.3	45.17±9.0
211	14.45±5.0	21.62±5.3	221	31.92±5.2	39.09±5.5	241	26.20±4.8	33.37±5.1
411	16.06±5.1	−1.32±6.1	421	22.35±7.0	4.97±7.7	441	24.94±2.7	7.56±4.3
Mean	13.37±2.2	16.17±3.0	Mean	26.87±2.7	29.67±3.2	Mean	30.33±2.4	33.12±3.1
012	17.99±5.0	16.36±5.2	022	18.52±4.6	16.89±4.9	042	37.28±4.5	35.65±4.8
112	34.73±5.3	32.84±7.1	122	44.47±8.1	42.58±9.4	142	40.11±5.8	38.22±7.5
212	31.95±6.3	34.86±7.9	222	29.03±5.2	32.84±7.1	242	25.66±7.3	28.57±8.7
412	12.14±3.3	15.15±5.4	422	32.04±3.2	35.05±5.4	442	13.13±3.1	16.14±5.3
Mean	24.20±2.5	24.80±3.2	Mean	31.24±2.8	31.84±3.4	Mean	29.04±2.7	29.64±3.4
014	27.62±5.4	24.04±6.3	024	21.36±3.4	17.78±4.7	044	43.50±6.5	39.92±7.2
114	38.54±5.1	43.24±6.4	124	31.11±5.3	35.81±6.6	144	55.58±7.7	60.28±8.6
214	25.10±5.2	19.78±7.9	224	16.50±5.9	11.18±8.3	244	27.27±3.1	21.95±6.7
414	30.12±7.0	32.36±7.9	424	35.53±2.5	37.77±4.5	444	5.89±3.1	8.13±4.8
Mean	30.34±2.9	29.86±3.6	Mean	26.12±2.2	25.64±3.1	Mean	33.06±2.7	32.57±3.5

GREEN SWEET-CORN FODDER

010	15.64± 4.0	15.64± 4.0	020	11.46± 4.1	11.46± 4.1	040	1.26±31.5	1.26±31.5
110	14.71± 3.6	4.97± 8.9	120	13.91± 3.3	4.17± 8.7	140	23.09± 4.9	13.35± 9.5
210	1.01± 5.0	5.87± 5.8	220	7.74± 4.6	12.60± 5.5	240	38.06± 5.4	42.92± 6.2
410	−1.55± 7.8	.03± 8.2	420	31.56± 6.0	33.14± 6.6	440	26.32± 4.9	27.90± 5.5
Mean	7.45± 2.7	6.63± 3.5	Mean	16.17± 2.3	15.34± 3.2	Mean	22.18± 8.2	21.36± 8.5
011	10.97± 3.8	23.21± 8.1	021	23.18± 4.0	35.42± 8.2	041	32.29±. 5.2	44.53± 8.9
111	−1.77± 3.0	−3.86± 7.6	121	26.66± 5.7	24.57± 9.0	141	35.46± 5.7	33.37± 9.0
211	10.04± 3.1	15.29± 4.2	221	27.78± 4.8	33.03± 5.6	241	33.20± 6.0	38.45± 6.6
411	18.05± 4.2	.142± 6.1	421	13.65± 6.2	−2.98± 7.6	441	34.85± 5.9	18.22± 7.4
Mean	9.32± 1.8	9.02± 3.3	Mean	22.82± 2.6	22.51± 3.8	Mean	33.95± 2.8	33.64± 4.0
012	13.58± 4.4	8.51± 5.6	022	25.62± 5.3	20.55± 6.3	042	33.02± 5.7	27.95± 6.6
112	42.34± 5.3	14.12± 6.7	122	34.30± 6.5	6.08± 7.7	142	48.45± 4.4	20.23± 6.0
212	19.79± 6.4	19.99± 9.2	222	38.69± 4.7	38.89± 8.1	242	40.71± 6.7	40.91± 9.4
412	19.45± 5.1	13.19± 6.8	422	35.15± 4.5	28.89± 6.4	442	21.74± 2.6	15.48± 5.2
Mean	23.79± 2.7	13.95± 3.6	Mean	33.44± 2.6	23.60± 3.6	Mean	35.98± 2.5	26.14± 3.5
014	39.36± 5.0	41.80± 6.1	024	33.74± 5.0	36.18± 6.1	044	47.62± 5.2	50.06± 6.3
114	35.91± 3.8	28.21± 6.7	124	36.24± 6.4	28.54± 8.4	144	68.36± 8.6	60.66±10.2
214	29.81± 4.4	5.15± 7.4	224	42.88± 5.4	18.22± 8.1	244	52.05± 5.2	27.39± 7.9
414	29.89± 6.0	32.26± 7.6	424	40.80± 4.6	43.17± 6.6	444	19.01± 3.5	21.38± 5.9
Mean	33.74± 2.4	26.86± 3.5	Mean	38.42± 2.7	31.53± 3.7	Mean	46.76± 3.0	39.87± 3.9

In Figure 9, A and B, the modes for the two sets of curves are as follows:

014, 021, and 041.
X14, {X22 and X41. X44.

Treatments X22 and X44 are bracketed together, as the ratios of P and K are identical. Treatment 021 is somewhat out of line in the comparisons made later. The relationship between phosphorus and potash, especially on the basis of the mean factors, is as follows:

P_2O_5-K	Pounds P_2O_5	Pounds K_2O
1–4	32	100
2–2	64	50
4–1	128	25

The mean factors for these treatments are also quite similar, namely, 29.86 ± 3.6 for X14, 31.84 ± 3.4 for X22, and 33.12 ± 3.1 for X41. According to this, phosphorus and potash seem to have an inverse relationship that is more marked when nitrogen is included than when it is omitted.

The data showing the effect of potash on the efficiency of phosphorus as determined by green fodder (figs. 9, C, D, and 10, C, D) are derived from Table 6.

The curves in Figure 9, C, although consistently irregular, show that on the fodder basis the efficiency of phosphorus tends to increase in relation to the amount of potash applied, the heaviest potash treatment being the mode of each curve. The mean factors in Figure 9, D, show the same relationship, and the modes coincide with the highest potash dosage. This relationship, based on green fodder, is direct and comparatively simple when contrasted with the inverse relationship shown by the same series on the ear basis.

Increasing dosages of phosphorus tend to increase the efficiency of this element on the fodder basis under all conditions (fig. 10, C and D), except where phosphorus is applied alone in the series 010–020–040. The modes all contain quadruple phosphorus except treatment 010.

From the preceding discussion it appears that the efficiency of phosphorus is modified materially by potash both indirectly and directly. The tendencies mentioned are summarized in the following statements.

Indirect Effect of Potash on the Efficiency of Phosphorus

On the basis of edible ears, but not on the fodder basis, increasing applications of potash tend to maintain an equivalent efficiency in relation to decreases in the amount of phosphorus used, this inverse relationship being limited to the mean factors in which nitrogen is included. (Fig. 9, B.)

In mixtures of phosphorus and potash, nitrogen omitted, the single dosage of potash is, in general, practically as efficient as heavier applications as determined by edible ears, or more so. (Fig. 9, A.)

Direct Effect of Potash on the Efficiency of Phosphorus

On the green-fodder basis, the efficiency of phosphorus is found to increase directly in relation to the application of potash both in phosphorus-potash combinations and in those including nitrogen, namely, the mean factors. (Fig. 9, C and D.)

The efficiency of phosphorus when applied alone tends to decrease in relation to successive increases in the amount applied, such decreases being much more marked in the case of green fodder than in the case of edible ears. (Fig. 10, A and C.)

The efficiency of phosphorus tends to increase directly in relation to added increments of this element in phosphorus-potash mixtures containing no nitrogen, on the basis of both edible ears and fodder. (Fig. 10, A and C.)

Phosphorus shows the same tendency when nitrogen is included, as determined by the mean factors, except that a single discrepancy occurs in Figure 10, B, with reference to edible ears, treatment X22 being slightly higher than X42. (Fig. 10, B and D.)

EFFECT OF PHOSPHORUS ON THE EFFICIENCY OF POTASH

The data on the effect of phosphorus on the efficiency of potash are given in Table 7 and Figures 11 and 12. In view of the inverse relationship between phosphorus and potash, discussed under phosphorus efficiency, a similar relationship might be expected when potash efficiency is considered.

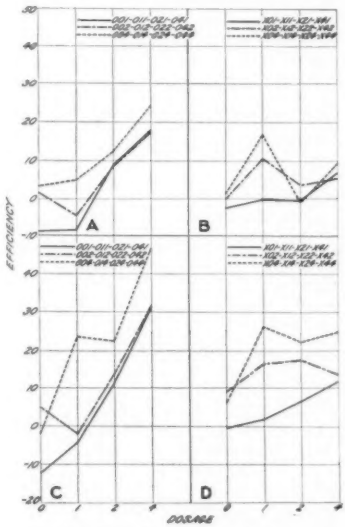

FIGURE 11.—The effect of successive increments of phosphorus on the efficiency of potash, both with and without nitrogen; results for two elements shown in A and C, for three elements in B and D, for edible ears in A and B, and for green fodder in C and D

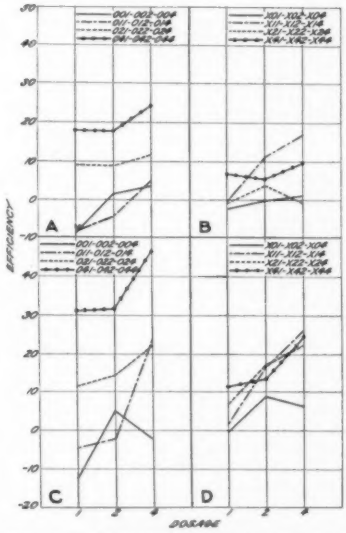

FIGURE 12.—The effect of successive increments of potash on its efficiency in phosphorus-potash combinations, both with and without nitrogen; results for two elements shown in A and C, for three elements in B and D, for edible ears in A and B, and for green fodder in C and D

According to Figure 11, A and C, the efficiency of potash based both on edible ears and on green fodder shows a tendency to increase in relation to successive additions of phosphorus when used in combinations of phosphorus and potash. As shown in the above tabulation, the mode of each curve coincides with the largest amount of

phosphorus used. The value of these factors as used in this interpretation must be qualified, of course, by the fact that the probable errors in most instances are large, and especially so in the case of fodder.

TABLE 7.—*Comparison of the effects of phosphorus on the mean percentage increases in yields of edible green sweet corn and of sweet-corn fodder, and on the efficiency of potash, basis of percentages*

EDIBLE GREEN SWEET CORN

Treatment	Increase in yield	K efficiency factor	Treatment	Increase in yield	K efficiency factor	Treatment	Increase in yield	K efficiency factor
001	−8.98±2.7	−8.98±2.7	002	1.63±1.6	1.63±1.6	004	3.58±3.2	3.58±3.2
101	−12.41±6.5	−17.92±8.2	102	1.89±4.7	−3.62±6.9	104	−4.70±3.9	−10.21±6.3
201	−7.17±1.8	−4.26±2.8	202	−2.91±4.8	0	204	5.32±5.9	8.23±6.3
401	17.38±3.3	22.23±4.2	402	−3.01±4.3	1.84±5.0	404	−2.24±3.7	2.61±4.5
Mean	−2.80±2.0	−2.23±2.5	Mean	−.60±2.0	−.04±3.1	Mean	.49±2.2	1.05±2.6
011	13.91±4.0	−8.72±6.2	012	17.99±5.0	−4.64±6.9	014	27.62±5.4	4.99±7.2
111	9.07±3.5	−3.55±4.4	112	34.73±5.3	22.11±5.9	114	38.54±5.1	25.92±5.8
211	14.45±5.0	9.49±7.4	212	31.95±6.3	26.99±8.4	214	25.10±5.2	20.14±7.6
411	16.06±5.1	1.25±7.1	412	12.14±3.3	−2.67±5.9	414	30.12±7.0	15.31±8.5
Mean	13.37±2.2	−.38±3.2	Mean	24.20±2.5	10.45±3.4	Mean	30.34±2.9	16.59±3.7
021	18.75±4.3	8.73±5.1	022	18.52±4.6	8.50±5.3	024	21.36±3.4	11.34±4.3
121	34.47±4.7	5.54±6.1	122	44.47±8.1	15.54±9.0	124	31.11±5.3	2.18±6.6
221	31.92±5.2	.42±7.1	222	29.93±5.2	−1.57±7.1	224	16.50±5.9	−15.00±7.6
421	22.35±7.0	−16.63±8.3	422	32.04±3.2	−6.94±5.4	424	35.53±2.5	−3.45±5.1
Mean	26.87±2.7	−.48±3.4	Mean	31.24±2.8	3.88±3.4	Mean	26.12±2.2	−1.23±3.0
041	37.41±4.8	17.96±6.2	042	37.28±4.5	17.83±6.0	044	43.50±6.5	24.05±7.6
141	32.76±6.3	2.64±8.8	142	40.11±5.8	9.99±8.4	144	55.58±7.7	25.46±9.8
241	26.20±4.8	−2.96±6.3	242	25.66±7.3	−3.50±8.4	244	27.27±3.1	−1.89±5.1
441	24.94±2.7	9.21±4.8	442	13.13±3.1	−2.60±5.1	444	5.89±3.1	−9.84±5.1
Mean	30.33±2.4	6.71±3.3	Mean	29.04±2.7	5.43±3.6	Mean	33.06±2.7	9.44±3.6

GREEN SWEET-CORN FODDER

001	−12.24±7.2	−12.24± 7.2	002	5.07±3.4	5.07± 3.4	004	−2.44±3.5	−2.44±3.5
101	2.09±7.0	−7.65±10.7	102	28.22±4.1	18.48± 9.1	104	7.70±5.5	−2.04± 9.8
201	−5.25±2.8	−.39± 4.1	202	−.20±6.6	4.66± 7.2	204	24.66±6.0	29.52± 6.7
401	16.63±4.4	18.21± 5.1	402	6.26±4.5	7.84± 5.2	404	−2.37±4.7	−.79± 5.4
Mean	.31±2.8	−.52±3.6	Mean	9.84±2.4	9.01± 3.3	Mean	6.89±2.6	6.06± 3.4
011	10.97±3.8	−4.67± 5.5	012	13.58±4.4	−2.06± 5.9	014	39.36±5.0	23.72± 6.4
111	−1.77±3.0	−16.48± 4.7	112	42.34±5.3	27.63± 6.4	114	35.91±3.8	21.20± 5.2
211	10.04±3.1	9.03± 5.9	212	19.79±6.4	18.78± 8.1	214	29.81±4.4	28.80± 6.7
411	18.05±4.2	19.60± 8.9	412	19.45±5.1	21.00± 9.3	414	29.89±6.0	31.44± 9.8
	9.32±1.8	1.87± 3.2	Mean	23.79. ±27	16.34± 3.8	Mean	33.74±2.4	26.29± 3.6
021	23.18±4.0	11.72± 5.7	022	25.62±5.3	14.16± 6.8	024	33.74±5.0	22.28± 6.5
121	26.66±5.7	12.75± 6.6	122	34.30±6.5	20.39± 7.3	124	36.24±6.4	22.33± 7.2
221	27.78±4.8	20.04± 6.6	222	38.69±4.7	30.95± 6.6	224	42.88±5.4	35.14± 7.1
421	13.65±6.2	−17.91± 8.7	422	35.15±4.5	3.59± 7.6	424	40.80±4.6	9.24± 7.6
Mean	22.82±2.6	6.65± 3.5	Mean	33.44±2.6	17.27± 3.5	Mean	38.42±2.7	22.25± 3.6
041	32.29±5.2	31.03± 3.9	042	33.02±5.7	31.76±32.0	044	47.62±5.2	46.36±31.9
141	35.46±5.7	12.37± 7.5	142	48.45±4.4	25.36± 6.6	144	68.36±8.6	48.27± 9.9
241	33.20±5.4	−4.86± 8.1	242	40.71±6.7	2.65± 8.6	244	52.05±5.2	13.99± 7.5
441	34.85±5.9	8.53± 7.7	442	21.74±2.6	−4.58± 5.5	444	19.01±3.5	−7.31± 6.0
Mean	33.95±2.8	11.77± 3.5	Mean	35.98±2.5	13.80± 8.6	Mean	46.76±3.0	24.58± 8.7

According to Figure 12, A and C, there is more or less of a tendency for the efficiency of potash to increase in relation to the amount applied in phosphorus-potash mixtures based on both ears and fodder. When compared the modes of each curve confirm this, but the probable errors in several cases are very large indeed.

The curves of the mean factors, where nitrogen is included (fig. 11, B and D), show the influence of the inverse relationship between phosphorus and potash confirmed by the modes of each curve, namely, X41, X12, and X14 in the case of edible ears, and X41, X22, and X14 in the case of fodder. The mode X12 is out of line and should be X22. Four of these modes are more than three and two-tenths times their probable errors, one is more than three times, and another is twice its probable error.

The curves in Figure 12, B, consisting of the mean efficiency factors, show a tendency for the efficiency of potash to increase in relation to the amount applied. Only one of the modes, X14, is statistically significant, however. A similar tendency is indicated by fodder in Figure 12, D, but here the modes of each curve appear to be more significant.

In mixtures of phosphorus and potash, the tendency of potash to increase in efficiency is related (1) to successive increases in the amount of phosphorus applied, and (2) to successive increases in the amount of potash used. The mean factors when compared with respect to increasing dosages of phosphorus (fig. 11, B and D) show an inverse relationship, but when compared with respect to increasing dosages of potash (fig. 12, B and D), the maximum efficiency seems to be associated largely with the highest application of potash. From this it appears that while there is a tendency for phosphorus and potash to be inversely related on the basis of potash efficiency, such a tendency is by no means as strong or as consistent as the inverse relationship between these two elements based on phosphorus efficiency.

GENERAL DISCUSSION

The crop data have been interpreted by means of certain theoretical factors called efficiency factors. These factors show that each of the three nutrient elements essential to plant life is influenced by additions of salts containing one or two of the others. No attempt will be made to explain the causes of the phenomena observed. Whether they are due to changes in the availability of one fertilizer salt following the addition of one or two others is a matter of opinion that is outside the scope of this article. At the same time it should be understood that no claim is made concerning the probability that certain trends and tendencies observed in this experiment are applicable outside the limits of this experiment. The purpose of the discussion which follows is to correlate the apparently diverse trends of the efficiency factors in such a manner that the optimum fertilizer ratios of this experiment may be definitely determined.

The efficiency of nitrogen is influenced very materially by the presence of phosphorus and potash used in combination with it. Under the conditions of this experiment, nitrogen applied alone around the hill of corn has an efficiency which is slightly above or below zero. Preceding this top-dressing with a basal treatment of phosphorus gives variable results. If this basal treatment consists of 32 pounds P_2O_5 per acre the efficiency of nitrogen is depressed even further, but not to the extent of being statistically significant. Doubling the basal phosphorus treatment to 64 pounds P_2O_5 per acre gives very large increases in nitrogen efficiency, which in the case of edible ears are significant in all nitrogen combinations. Quadrupling the

In Figure 9, A and B, the modes for the two sets of curves are as follows:

014, 021, and 041.
X14, {X22 and X41. X44.

Treatments X22 and X44 are bracketed together, as the ratios of P and K are identical. Treatment 021 is somewhat out of line in the comparisons made later. The relationship between phosphorus and potash, especially on the basis of the mean factors, is as follows:

P_2O_5-K	Pounds P_2O_5	Pounds K_2O
1–4	32	100
2–2	64	50
4–1	128	25

The mean factors for these treatments are also quite similar, namely, 29.86 ± 3.6 for X14, 31.84 ± 3.4 for X22, and 33.12 ± 3.1 for X41. According to this, phosphorus and potash seem to have an inverse relationship that is more marked when nitrogen is included than when it is omitted.

The data showing the effect of potash on the efficiency of phosphorus as determined by green fodder (figs. 9, C, D, and 10, C, D) are derived from Table 6.

The curves in Figure 9, C, although consistently irregular, show that on the fodder basis the efficiency of phosphorus tends to increase in relation to the amount of potash applied, the heaviest potash treatment being the mode of each curve. The mean factors in Figure 9, D, show the same relationship, and the modes coincide with the highest potash dosage. This relationship, based on green fodder, is direct and comparatively simple when contrasted with the inverse relationship shown by the same series on the ear basis.

Increasing dosages of phosphorus tend to increase the efficiency of this element on the fodder basis under all conditions (fig. 10, C and D), except where phosphorus is applied alone in the series 010–020–040. The modes all contain quadruple phosphorus except treatment 010.

From the preceding discussion it appears that the efficiency of phosphorus is modified materially by potash both indirectly and directly. The tendencies mentioned are summarized in the following statements.

Indirect Effect of Potash on the Efficiency of Phosphorus

On the basis of edible ears, but not on the fodder basis, increasing applications of potash tend to maintain an equivalent efficiency in relation to decreases in the amount of phosphorus used, this inverse relationship being limited to the mean factors in which nitrogen is included. (Fig. 9, B.)

In mixtures of phosphorus and potash, nitrogen omitted, the single dosage of potash is, in general, practically as efficient as heavier applications as determined by edible ears, or more so. (Fig. 9, A.)

Direct Effect of Potash on the Efficiency of Phosphorus

On the green-fodder basis, the efficiency of phosphorus is found to increase directly in relation to the application of potash both in phosphorus-potash combinations and in those including nitrogen, namely, the mean factors. (Fig. 9, C and D.)

The efficiency of phosphorus when applied alone tends to decrease in relation to successive increases in the amount applied, such decreases being much more marked in the case of green fodder than in the case of edible ears. (Fig. 10, A and C.)

The efficiency of phosphorus tends to increase directly in relation to added increments of this element in phosphorus-potash mixtures containing no nitrogen, on the basis of both edible ears and fodder. (Fig. 10, A and C.)

Phosphorus shows the same tendency when nitrogen is included, as determined by the mean factors, except that a single discrepancy occurs in Figure 10, B, with reference to edible ears, treatment X22 being slightly higher than X42. (Fig. 10, B and D.)

EFFECT OF PHOSPHORUS ON THE EFFICIENCY OF POTASH

The data on the effect of phosphorus on the efficiency of potash are given in Table 7 and Figures 11 and 12. In view of the inverse relationship between phosphorus and potash, discussed under phosphorus efficiency, a similar relationship might be expected when potash efficiency is considered.

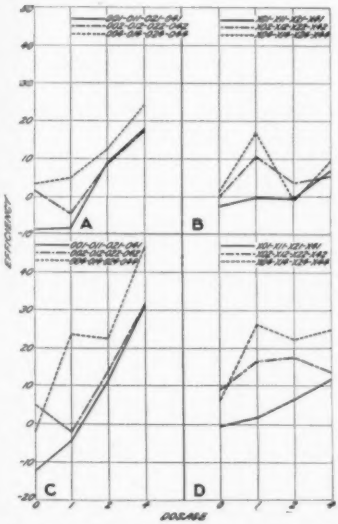

FIGURE 11.—The effect of successive increments of phosphorus on the efficiency of potash, both with and without nitrogen; results for two elements shown in A and C, for three elements in B and D, for edible ears in A and B, and for green fodder in C and D

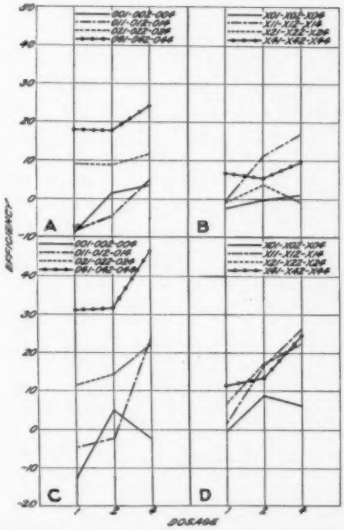

FIGURE 12.—The effect of successive increments of potash on its efficiency in phosphorus-potash combinations, both with and without nitrogen; results for two elements shown in A and C, for three elements in B and D, for edible ears in A and B, and for green fodder in C and D

According to Figure 11, A and C, the efficiency of potash based both on edible ears and on green fodder shows a tendency to increase in relation to successive additions of phosphorus when used in combinations of phosphorus and potash. As shown in the above tabulation, the mode of each curve coincides with the largest amount of

phosphorus used. The value of these factors as used in this interpretation must be qualified, of course, by the fact that the probable errors in most instances are large, and especially so in the case of fodder.

TABLE 7.—*Comparison of the effects of phosphorus on the mean percentage increases in yields of edible green sweet corn and of sweet-corn fodder, and on the efficiency of potash, basis of percentages*

EDIBLE GREEN SWEET CORN

Treatment	Increase in yield	K efficiency factor	Treatment	Increase in yield	K efficiency factor	Treatment	Increase in yield	K efficiency factor
001	−8.98±2.7	−8.98±2.7	002	1.63±1.6	1.63±1.6	004	3.58±3.2	3.58±3.2
101	−12.41±6.5	−17.92±8.2	102	1.89±4.7	−3.62±6.9	104	−4.70±3.9	−10.21±6.3
201	−7.17±1.8	−4.26±2.8	202	−2.91±4.8	0	204	5.32±5.9	8.23±6.3
401	17.38±3.3	22.23±4.2	402	−3.01±4.3	1.84±5.0	404	−2.24±3.7	2.61±4.5
Mean	−2.80±2.0	−2.23±2.5	Mean	−.60±2.0	−.04±3.1	Mean	.49±2.2	1.05±2.6
011	13.91±4.0	−8.72±6.2	012	17.99±5.0	−4.64±6.9	014	27.62±5.4	4.99±7.2
111	9.07±3.5	−3.55±4.4	112	34.73±5.3	22.11±5.9	114	38.54±5.1	25.92±5.8
211	14.45±5.0	9.49±7.4	212	31.95±6.3	26.99±8.4	214	25.10±5.2	20.14±7.6
411	16.06±5.1	1.25±7.1	412	12.14±3.3	−2.67±5.9	414	30.12±7.0	15.31±8.5
Mean	13.37±2.2	−.38±3.2	Mean	24.20±2.5	10.45±3.4	Mean	30.34±2.9	16.59±3.7
021	18.75±4.3	8.73±5.1	022	18.52±4.6	8.50±5.3	024	21.36±3.4	11.34±4.3
121	34.47±4.7	5.54±6.1	122	44.47±8.1	15.54±9.0	124	31.11±5.3	2.18±6.6
221	31.92±5.2	.42±7.1	222	29.93±5.2	−1.57±7.1	224	16.50±5.9	−15.00±7.6
421	22.35±7.0	−16.63±8.3	422	32.04±3.2	−6.94±5.4	424	35.53±2.5	−3.45±5.1
Mean	26.87±2.7	−.48±3.4	Mean	31.24±2.8	3.88±3.4	Mean	26.12±2.2	−1.23±3.0
041	37.41±4.8	17.96±6.2	042	37.28±4.5	17.83±6.0	044	43.50±6.5	24.05±7.6
141	32.76±6.3	2.64±8.8	142	40.11±5.8	9.99±8.4	144	55.58±7.7	25.46±9.8
241	26.20±4.8	−2.96±6.3	242	25.66±7.3	−3.50±8.4	244	27.27±3.1	−1.89±5.1
441	24.94±2.7	9.21±4.8	442	13.13±3.1	−2.60±5.1	444	5.89±3.1	−9.84±5.1
Mean	30.33±2.4	6.71±3.3	Mean	29.04±2.7	5.43±3.6	Mean	33.06±2.7	9.44±3.6

GREEN SWEET-CORN FODDER

001	−12.24±7.2	−12.24± 7.2	002	5.07±3.4	5.07± 3.4	004	−2.44±3.5	−2.44±3.5
101	2.09±7.0	−7.65±10.7	102	28.22±4.1	18.48± 9.1	104	7.70±5.5	−2.04± 9.8
201	−5.25±2.8	−.39± 4.1	202	−.20±6.6	4.66± 7.2	204	24.66±6.0	29.52± 6.7
401	16.63±4.4	18.21± 5.1	402	6.26±4.5	7.84± 5.2	404	−2.37±4.7	−.79± 5.4
Mean	.31±2.8	−.52±3.6	Mean	9.84±2.4	9.01± 3.3	Mean	6.89±2.6	6.06± 3.4
011	10.97±3.8	−4.67± 5.5	012	13.58±4.4	−2.06± 5.9	014	39.36±5.0	23.72± 6.4
111	−1.77±3.0	−16.48± 4.7	112	42.34±5.3	27.63± 6.4	114	35.91±3.8	21.20± 5.2
211	10.04±3.1	9.03± 5.9	212	19.79±6.4	18.78± 8.1	214	29.81±4.4	28.80± 6.7
411	18.05±4.2	19.60± 8.9	412	19.45±5.1	21.00± 9.3	414	29.89±6.0	31.44± 9.8
	9.32±1.8	1.87± 3.2	Mean	23.79. ±27	16.34± 3.8	Mean	33.74±2.4	26.29± 3.6
021	23.18±4.0	11.72± 5.7	022	25.62±5.3	14.16± 6.8	024	33.74±5.0	22.28± 6.5
121	26.66±5.7	12.75± 6.6	122	34.30±6.5	20.39± 7.3	124	36.24±6.4	22.33± 7.2
221	27.78±4.8	20.04± 6.6	222	38.69±4.7	30.95± 6.6	224	42.88±5.4	35.14± 7.1
421	13.65±6.2	−17.91± 8.7	422	35.15±4.5	3.59± 7.6	424	40.80±4.6	9.24± 7.6
Mean	22.82±2.6	6.65± 3.5	Mean	33.44±2.6	17.27± 3.5	Mean	38.42±2.7	22.25± 3.6
041	32.29±5.2	31.03± 3.9	042	33.02±5.7	31.76±32.0	044	47.62±5.2	46.36±31.9
141	35.46±5.7	12.37± 7.5	142	48.45±4.4	25.36± 6.6	144	68.36±8.6	45.27± 9.9
241	33.20±5.4	−4.86± 8.1	242	40.71±6.7	2.65± 8.6	244	52.05±5.2	13.99± 7.5
441	34.85±5.9	8.53± 7.7	442	21.74±2.6	−4.58± 5.5	444	19.01±3.5	−7.31± 6.0
Mean	33.95±2.8	11.77± 3.5	Mean	35.98±2.5	13.80± 8.6	Mean	46.76±3.0	24.58± 8.7

According to Figure 12, A and C, there is more or less of a tendency for the efficiency of potash to increase in relation to the amount applied in phosphorus-potash mixtures based on both ears and fodder. When compared the modes of each curve confirm this, but the probable errors in several cases are very large indeed.

The curves of the mean factors, where nitrogen is included (fig. 11, B and D), show the influence of the inverse relationship between phosphorus and potash confirmed by the modes of each curve, namely, X41, X12, and X14 in the case of edible ears, and X41, X22, and X14 in the case of fodder. The mode X12 is out of line and should be X22. Four of these modes are more than three and two-tenths times their probable errors, one is more than three times, and another is twice its probable error.

The curves in Figure 12, B, consisting of the mean efficiency factors, show a tendency for the efficiency of potash to increase in relation to the amount applied. Only one of the modes, X14, is statistically significant, however. A similar tendency is indicated by fodder in Figure 12, D, but here the modes of each curve appear to be more significant.

In mixtures of phosphorus and potash, the tendency of potash to increase in efficiency is related (1) to successive increases in the amount of phosphorus applied, and (2) to successive increases in the amount of potash used. The mean factors when compared with respect to increasing dosages of phosphorus (fig. 11, B and D) show an inverse relationship, but when compared with respect to increasing dosages of potash (fig. 12, B and D), the maximum efficiency seems to be associated largely with the highest application of potash. From this it appears that while there is a tendency for phosphorus and potash to be inversely related on the basis of potash efficiency, such a tendency is by no means as strong or as consistent as the inverse relationship between these two elements based on phosphorus efficiency.

GENERAL DISCUSSION

The crop data have been interpreted by means of certain theoretical factors called efficiency factors. These factors show that each of the three nutrient elements essential to plant life is influenced by additions of salts containing one or two of the others. No attempt will be made to explain the causes of the phenomena observed. Whether they are due to changes in the availability of one fertilizer salt following the addition of one or two others is a matter of opinion that is outside the scope of this article. At the same time it should be understood that no claim is made concerning the probability that certain trends and tendencies observed in this experiment are applicable outside the limits of this experiment. The purpose of the discussion which follows is to correlate the apparently diverse trends of the efficiency factors in such a manner that the optimum fertilizer ratios of this experiment may be definitely determined.

The efficiency of nitrogen is influenced very materially by the presence of phosphorus and potash used in combination with it. Under the conditions of this experiment, nitrogen applied alone around the hill of corn has an efficiency which is slightly above or below zero. Preceding this top-dressing with a basal treatment of phosphorus gives variable results. If this basal treatment consists of 32 pounds P_2O_5 per acre the efficiency of nitrogen is depressed even further, but not to the extent of being statistically significant. Doubling the basal phosphorus treatment to 64 pounds P_2O_5 per acre gives very large increases in nitrogen efficiency, which in the case of edible ears are significant in all nitrogen combinations. Quadrupling the

phosphorus treatment to 128 pounds P_2O_5 per acre depresses the efficiency of nitrogen below the 64 pounds of P_2O_5 treatment in the case of edible ears but increases it in the case of fodder. However, none of the factors involving the basal treatment of 64 and 128 pounds of P_2O_5 as determined by fodder are significant. The mean factors which include the average of the potash additions show, with minor variations, substantially similar trends, with statistical significance almost entirely confined to the double phosphorus treatment, based on edible ears. The effect of increasing increments of nitrogen upon the efficiency of this element is somewhat variable. Significant results are obtained in only two instances, and both of these are based on edible ears. When combined with 64 pounds P_2O_5 per acre, nitrogen increases in efficiency as the dosage increases. The mean factors, however, show that the single nitrogen dosage is just as efficient as heavier applications. The remaining data also show that the single nitrogen dosage tends to be the most efficient.

Two points of major importance are brought out by this discussion. These are (1) that nitrogen, except where combined with an apparently optimum phosphorus dosage, tends to give the maximum efficiency when applied in quantities of not more than 7.5 pounds per acre, and (2) in order to obtain the highest efficiency, the nitrogen dosage must be combined with the double phosphorous dosage. This establishes the limits in this experiment for the use of nitrogen as determined by its relationship with phosphorus. It would be very difficult, indeed, to determine these facts with certainty from even a thorough study of the yields in Table 1.

The efficiency of nitrogen is also strongly influenced by the presence of a potash salt. The data show that this influence is reciprocal; in other words, the efficiency of potash seems to be affected by nitrogen in substantially the same manner as the efficiency of nitrogen is affected by potash. For this reason, the reciprocal efficiency of both of these elements will be discussed together. Although not entirely free from discrepancies, and qualified by the fact that the probable errors are very large, the curves in many instances show that the maximum efficiencies of both nitrogen and potash are associated in the following combinations: (1) 7½ pounds nitrogen per acre side dressed after a basal treatment of 50 pounds K_2O per acre; (2) 15 pounds of nitrogen per acre side dressed after a basal treatment of 100 pounds K_2O per acre; and (3) 30 pounds of nitrogen per acre side dressed after a basal treatment of 25 pounds K_2O per acre.

Most of the factors for nitrogen efficiency as affected by potash and, inversely, potash efficiency as affected by nitrogen, are unreliable because of their large probable errors, but it should be noted that the statistically significant ones are practically all confined to the three ratios mentioned. Of these three, namely, 7.5–0–50, 15–0–100, and 30–0–25, the first two are the same except as to quantity. The last, 30–0–25, conforms approximately with commercial analyses such as 2–12–2, 4–16–4, etc., commonly used in Illinois and in other parts of the Central West, but the others are not in extensive commercial use. The data which have been presented show (1) that in combinations of nitrogen and potash, with phosphorus omitted with the 30–0–25 ratio is considerably more efficient than the other two ratios on the basis of edible ears and about equally so on the green-fodder basis; (2) that the mean factors which include phosphorus prove the 7.5–0–50 ratio

to be superior on the basis of both ears and fodder. It is therefore apparent that only two ratios of nitrogen and potash need be considered, a 30–0–25 and a 7.5–0–50, the latter being apparently superior to the former in complete analyses.

The discussion thus far has definitely limited the types of fertilizer analyses which might be expected to give optimum results. The requirements for an optimum analysis may be stated as follows: (1) Not more than 7.5 pounds of nitrogen per acre should be applied as a side dressing; (2) when nitrogen is used, this element gives the highest efficiency if combined with the double phosphorus application of 64 pounds P_2O_5 per acre; and (3) the ratio of nitrogen and potash that gives the best results in a phosphorus-bearing fertilizer is 7.5:50.

A fertilizer answering the above requirements would be a 7.5–64–50 in terms of plant food per acre. Before concluding that such a combination will fully answer the requirements of the soils in this experiment, a consideration of the efficiency of phosphorus is necessary.

The efficiency of phosphorus is influenced appreciably by the amount applied to the soil and also by the use of nitrogen in connection with it. Nitrogen acts in general as a depressive agent when side dressed after an application of 32 pounds P_2O_5 per acre; but when the application is increased to 64 or 128 pounds per acre, side dressings of 7.5 to 15 pounds nitrogen per acre are quite consistent in increasing the efficiency of phosphorus. These trends apply to nitrogen-phosphorus combinations. The mean efficiency factors have somewhat different trends. Based on edible ears, the single dosage of nitrogen is the most efficient, but as determined by green fodder, nitrogen has but little effect.

The efficiency of phosphorus changes materially in relation to the amount applied. Phosphorus alone tends to decrease in efficiency as successively larger amounts are applied. In nitrogen-phosphorus mixtures the tendency for phosphorus to increase in efficiency in relation to successive additions is quite marked. In general, 64 pounds P_2O_5 per acre is the most efficient on the edible-ear basis and from 64 to 128 pounds on the fodder basis. Although differing in some respects, the mean factors show substantially the same trends.

Since the efficiency factors just discussed are in most instances significant from the statistical standpoint, certain definite information is added concerning the optimum fertilizers in these experiments. It is obvious that nitrogen should not be used unless the phosphorus requirements are satisfied. Other important points brought out are (1) 7.5 pounds of nitrogen per acre is sufficient if it supplements both minerals, (2) 64 pounds P_2O_5 per acre may be considered the optimum phosphorus application, and (3) 32 pounds P_2O_5 per acre is the maximum application if phosphorus is to be used alone.

These trends justify the conclusion that 7.5 pounds N and 64 pounds P_2O_5 per acre is the combination that gives the optimum results. This is fully in accordance with the previous conclusion, that a 7.5–64–50 analysis on an acre basis gives the optimum results.

The efficiency of phosphorus is likewise modified to a considerable degree by potash, but green fodder and edible ears are not alike in their reaction. Considering the results with edible ears first, it has been found that on this basis there is a decided tendency for phosphorus and potash to bear an inverse relationship to each other, in which the mean efficiency factors tend to maintain an equilibrium as

the potash applications are increased and the phosphorus applications are decreased. (Table 8.) The mean factors are practically identical in size. In contrast, the efficiency of the single dosage of potash in mixtures of phosphorus and potash, omitting nitrogen, is as high as, or higher than, heavier applications, irrespective of the dosage of phosphorus.

TABLE 8.—*Inverse relationship between applications of phosphorus and potash as exemplified by equilibrim of the mean efficiency factors as potash applications are decreased and phosphorus applications increased*

[Figures relate to edible green sweet corn only]

Code	P_2O_5	K_2O	Efficiency factor
	Pounds per acre	*Pounds per acre*	
X14	32	100	29.86±3.6
X22	64	50	31.84±3.4
X41	128	25	33.12±3.1

On the basis of green fodder, it is found that the efficiency o phosphorus increases directly in relation to the application of potash in all types of mixtures.

In phosphorus-potash mixtures containing no nitrogen, the efficiency of phosphorus increases directly in relation to the amount of phosphorus used. In mixtures including nitrogen, the general tendency is similar, but there are some important variations.

These results are of considerable value in determining the optimum phosphorus-potash ratio. The results show that mixtures of the minerals only respond differently from complete-analysis fertilizers. In mixtures of the minerals only, the highest efficiency is obtained with the single potash dosage on the ear basis, but higher applications of potash are indicated on the fodder basis. Similarly, the efficiency of phosphorus increases in relation to the dosage on both bases. Thus when phosphorus-potash mixtures are used the 041 type of mixture would give the highest efficiency on the ear basis, and the 044 type on the fodder basis. Stated in terms of plant-food ratios, the 041 mixture is equivalent to 0–128–125 and the 044 to 0–128–100. The nearest commercial analyses now available would be, respectively, 0–16–3 and 0–16–12.

However, this is materially modified by the mean factors where nitrogen is also averaged. Here equivalent efficiencies on the ear basis are shown by three radically different mixtures, X14, X22, and X41, which are equivalent to mixtures of X–32–100, X–64–50, and X–128–25; or, in trade terms, X–8–24, X–16–12, and X–16–3, applied, of course, in different quantities, 400, 400, and 800 pounds, respectively. On the fodder basis, a mixture of the X44 (X–128–100) type might be preferred, as the efficiency of phosphorus reaches the maximum when the highest dosages are used in connection with the highest dosages of potash.

The question now remains as to how these data may be properly evaluated. Previous to the discussion of the effect of potash on the efficiency of phosphorus, the conclusion was reached that a 7.5–64–50

per acre analysis would give the optimum results. A summary of the types of mixtures that give the best results is presented in Table 9.

TABLE 9.—*Summary of types of fertilizer mixtures that give the best results with ear corn and fodder*

Basis and basal formula	Nearest commercial formula	Quantity per acre	Plant food per acre (N–P_2O_5–K_2O)
		Pounds	*Pounds*
Ear basis:			
0–5.1–1	0–16– 3	800	0–128– 25
Fodder basis:			
0–1.3–1	0–16–12	800	0–128–100
Ear basis:			
X–1–3.1	X– 8–24	400	X– 32–100
X–1.3–1	X–16–12	400	X– 64– 50
X–5.1–1	X–16– 3	800	X–128– 25
Fodder basis:			
X–1.3–1	X–16–12	800	X–128–100

Considering first the fertilizers containing nitrogen, the X–128–25 type might be eliminated because, in order to obtain an equivalent efficiency, 800 pounds must be used, as compared with half the quantity in certain other mixtures. The X–32–100 mixture may also be eliminated because the efficiency of 7.5 pounds of nitrogen per acre, combined with 32 pounds P_2O_5 per acre is very low, and likewise combinations of 7.5 pounds nitrogen and 100 pounds K_2O per acre are very much less efficient than those containing half as much potash. This leaves the X–64–50 combination, which apparently fulfills all the requirements and is consistent with the 7.5–64–50 type already mentioned as being the most desirable

Another type of mixture, because of its extensive use in Illinois, also requires discussion, that is, one containing only the minerals. Table 9 shows that the 0–128–25 is most efficient on the ear basis and the 0–128–100 on the fodder basis. The phosphorus efficiency factors of these mixtures on the fodder basis are, respectively, 44.53 ± 8.9 and 50.06 ± 6.3. (Table 6.) The difference is 5.53 ± 10.9, which is less than its probable error, and accordingly the 0–128–100 mixture may be eliminated. There is, however, one fundamental objection to the remaining 0–128–25 combination; it is an application much heavier than is customarily used in the Corn Belt for a low-value crop such as sweet corn. It is at this point that the experiment is weak, because there is no direct method of determining what the effect would be of halving the 0–128–25 treatment. The only alternative is to approximate the effect by indirect means. The treatments nearest to 0–128–25 are 0–128–0 and 0–128–50 (040 and 042). According to Table 6, the phosphorus efficiency of treatment 0–128–0 is only 19.45 ± 4.0, whereas that of 0–128–50 is 35.65 ± 4.8, or almost twice as large. If the respective half-size treatments 0–64–0 (020) and 0–64–25 (021) are compared (Table 6), the efficiencies are found to be 10.02 ± 2.7 and 27.73 ± 5.1. Clearly, potash, because it gives such a large increase in phosphorus efficiency, is essential, and 0–128–0 and 0–64–0 can not be considered as alternative treatments in place of 0–128–25. This leaves 0–64–25 (021), which in turn is considerably higher than 0–64–50 (022) in phosphorus

efficiency. Therefore, the only possible treatment smaller than 0–128–50 (041) which approaches it in efficiency is 0–64–25 (021). A comparison of these treatments based on the data in Table 6 is shown in Table 10.

TABLE 10.—*A comparison of two fertilizer treatments as to percentage increase in yield of ear corn and fodder and as to phosphorus efficiency factor*

Treatment	Percentage increase in yield of—		Phosphorus-efficiency factor for—	
	Ears	Fodder	Ears	Fodder
0–128–50 (041)	37.41±4.8	32.29±5.2	46.39±5.5	44.53± 8.9
0–64–25 (021)	18.75±4.3	23.18±4.0	27.73±5.1	35.42± 8.2
Difference	18.66±6.4	9.11±6.6	18.66±7.5	9.11±12.1

All the differences recorded are less than three and two-tenths times their probable errors, and while the yield increase of 041 is double that of 021 the difference is somewhat less than might be regarded as significant. Numerous subsequent experiments in many sections of Illinois have proved the correctness of the belief that the 021 (0–64–25) mixture is the more desirable. It is the only mixture now in commercial use on thousands of acres of sweet corn in Illinois. It is applied at the rate of 100 pounds per acre around the hill at planting in the form of an 0–16–6 analysis that is one-fourth of the 0–64–25. Broadcasting has never become popular.

Consideration remains to be given to the effect of phosphorus on the efficiency of potash. It may be said in general that phosphorus exerts a weaker and less consistent effect upon potash than nitrogen. Most of the recorded efficiency factors lack statistical significance, but certain trends develop which have some value. In mixtures of phosphorus and potash there is a tendency for potash to increase in efficiency with successive increments of both phosphorus and potash. The mean efficiency factors show an inverse relationship similar to that discussed under phosphorus efficiency, but this tendency is comparatively limited in scope and is not so consistent.

The repeated process of elimination has brought the possible optimum fertilizer treatments in this experiment down to three, namely, 0–64–25, 0–128–25, and 7.5–64–50. Their relation to the yield data may now be determined by studying the crop records of edible ears from the 10 best treatments in Table 1, as shown in Table 11.

Two of the three treatments selected as being the optimum appear in the table. Treatment 122 (7.5–5–64–50) is third in rank on the basis of increased ton yields, but second on the percentage basis. Treatment 041 (0–128–25) is sixth on the basis of increased ton yields and seventh on the percentage basis. Treatment 021 (0–64–25) does not appear at all, but its multiple 042 (0–128–50) ranks about the same as 041.

TABLE 11.—*Relation between the efficiency of the three optimum fertilizer treatments as determined from crop records of edible ears produced by the 10 best treatments recorded in Table 1*

Treatment	Relationship computed—					
	On basis of yields by weight			On basis of percentage increase in yield		
	Rank	Tons per acre increase over check	Student's odds	Treatment	Rank	Percentage increase over check
144	1	0.971±0.134	3,332:1	144	1	55.58±7.7
142	2	.797± .115	1,932:1	122	2	44.47±8.1
044	3	.776± .115	1,799:1	044	3	43.50±6.5
122	3	.776± .142	400:1	142	4	40.11±5.8
420	4	.736± .083	>9,999:1	420	5	38.98±4.4
042	5	.683± .082	>9,999:1	114	6	38.54±5.1
041	6	.673± .086	4,999:1	041	7	37.41±4.8
141	7	.651± .125	323:1	042	8	37.28±4.5
424	7	.651± .046	>9,999:1	424	9	35.53±2.5
240	8	.648± .091	1,499:1	112	10	34.73±5.2

It is obvious that treatment 7.5–64–50 is much superior to the other two on the yield basis, and it should be noted that as compared with other high ranking ratios it contains the smallest amount of plant food. Four hundred pounds per acre of a 0–16–12 fertilizer followed by a side dressing of 50 pounds of sodium nitrate per acre would be the equivalent commercial application, and as a result of this work this is the one especially recommended.

SUMMARY

By means of a critical analysis of certain theoretical factors called efficiency factors, calculated from experimental results represented by six years' crop yields from 389 separate plots, the optimum fertilizer treatments are determined from a mass of apparently irrelevant and inconsistent crop yields without resorting to supplementary tests. This analysis is essentially a study of the reciprocal effects of fertilizer salts upon each other as determined by crop yields and not by chemical analysis. The influence of fertilizer salts upon each other was found to follow certain definite trends, which may or may not have a wider application than the limits of this experiment. The reciprocal action of these salts is given.

Nitrogen has a tendency to depress the efficiency of phosphorus when the latter element is applied in apparently insufficient amounts as a part of various fertilizer combinations; but if adequate amounts of phosphorus are included, small supplementary treatments of nitrogen increase the efficiency of phosphorus. Phosphorus applied alone in increasing amounts shows successive decreases in efficiency, but when used in combination with nitrogen, or with both nitrogen and potash, there is a consistent increase in efficiency.

Phosphorus also influences the efficiency of nitrogen to a very considerable extent. When the phosphorus content in nitrogen-phosphorus mixtures and in complete fertilizers appears to be inadequate, the efficiency of nitrogen is depressed, but if it is adequate there is an appreciable increase in nitrogen efficiency. When applications of nitrogen are increased and phosphorus is held constant the smallest amounts of nitrogen are usually the most efficient.

A study of the relations between nitrogen and potash indicates that these two nutrients have a reciprocal effect upon each other, and fur-

thermore their relationship shows a tendency to be inverse, that is, under certain conditions high nitrogen and low potash have efficiency factors equivalent to those derived from low nitrogen and high potash. With the inclusion of phosphorus, however, a combination containing low nitrogen and high potash usually gives better results than one with high nitrogen and low potash.

Phosphorus, in addition to being materially affected by nitrogen, is also subject to considerable change due to potash. The effect of potash is somewhat complex and does not manifest itself in the same manner under all conditions. Considered in terms of the influence upon yields of edible ears, potash seems to be most efficient when applied in relatively small amounts in combinations with phosphorus, but omitting nitrogen. The addition of nitrogen, as well as potash, gives rise to an inverse relationship in which phosphorus seems to maintain its efficiency in equilibrium when the potash dosage increases inversely to that of phosphorus. Considered from the standpoint of plant growth as determined by weight of green fodder, the efficiency of phosphorus tends to increase directly in relation to successive additions of potash. In general, the efficiency of phosphorus in various mixtures tends to increase in relation to the amounts applied.

The efficiency of potash is influenced to some extent by phosphorus and tends to increase in mixtures of these two elements (nitrogen omitted) according to the amount of each applied. There is a slight tendency for potash in complete fertilizers to exhibit the same type of inverse relationship with phosphorus as that mentioned in the preceding paragraph.

From a study of the efficiency factors it has been found possible to determine the optimum fertilizer ratios in this experiment without having direct recourse to the crop yields. It is believed that this method of analysis will be a valuable aid to the soils investigator in studying his data.

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